IS 5878-1 (1971): Code of Practice for Construction of Tunnels, Part I: Precision Survey and Setting Out [WRD 14: Water Conductor Systems]

BLANK PAGE

(Reaffirmed 2000)

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART I PRECISION SURVEY AND SETTING OUT

Third Reprint NOVEMBER 1989

(Incorporating Amendment No. 1)

UDC 624.191.1

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 6

September 1971

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART I PRECISION SURVEY AND SETTING OUT

Water Conductor System Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE
Ramalayam, Pedder Road, Bombay 26

Members	*Representing*
SHRI N. M. CHAKRAVORTY	Damodar Valley Corporation, Dhanbad
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhra Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (CIVIL AND INVESTIGATION CIRCLE) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
DEPUTY DIRECTOR (DAMS I)	Central Water & Power Commission, New Delhi
DIRECTOR	Irrigation & Power Research Institute, Amritsar
DR GAJINDER SINGH (*Alternate*)	
SHRI D. DODDIAH	Public Works & Electricity Department, Government of Mysore
SHRI S. G. BALAKUNDRY (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong
SHRI R. G. GANDHI	The Hindustan Construction Co Ltd, Bombay
SHRI M. S. DEWAN (*Alternate*)	
SHRI K. C. GHOSAL	Sahu Cement Service, New Delhi
SHRI S. N. GUPTA	Central Board of Irrigation & Power, New Delhi
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra
SHRI R. S. KALE (*Alternate*)	
SHRI V. S. KRISHNASWAMY	Geological Survey of India, Calcutta
SHRI K. S. S. MURTHY	Ministry of Irrigation and Power
SHRI Y. G. PATEL	Patel Engineering Co Ltd, Bombay
SHRI C. K. CHOKSHI (*Alternate*)	
SHRI P. B. PATIL	Gammon India Private Ltd, Bombay
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh
SHRI J. E. VAZ	Public Works Department, Government of Tamil Nadu
SHRI J. WALTER (*Alternate*)	

(*Continued on page* 2)

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

(*Continued from page* 1)

Members	*Representing*
SHRI R. NAGARAJAN, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

SHRI BIMLESH KUMAR
Assistant Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra
Members	
SHRI C. K. CHOKSHI	Patel Engineering Co Ltd, Bombay
SHRI M. S. DEWAN	The Hindustan Construction Co Ltd, Bombay
SHRI K. C. GHOSAL	Sahu Cement Service, New Delhi
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI K. SHAMA RAO	Kerala State Electricity Board, Trivandrum
SHRI A. S. NARAYANAN (*Alternate*)	

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART I PRECISION SURVEY AND SETTING OUT

0. FOREWORD

0.1 This Indian Standard (Part I) was adopted by the Indian Standards Institution on 29 March 1971, after the draft finalized by the Water Conductor System Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The construction of tunnels involves a variety of problems. Because of the great longitudinal extent of the work, many different kinds of conditions are encountered which for maximum economy should be treated differently. Moreover, design of a work is based on assumptions regarding quality of work which would be obtained during construction. These assumptions hold good only if the material used and the work as actually executed are according to the specifications which are known to give desired results. This standard (with all its parts) is intended to serve as a guide to the engineer-in-charge of construction of tunnel projects. However, because of the complex nature of the subject, it has not been possible to cover all possible contingencies and the judgement of the engineer-in-charge is required in making a final choice of the method to be adopted depending upon the conditions prevailing at the site.

0.3 This Part covers methods of precision survey setting out the tunnel alignment. Since the excavation of tunnel is normally started from many faces for expedititious completion of the work, it is essential that the excavation proceeds precisely along the pre-determined alignment. Even a slight deviation from the correct alignment, particularly in the initial stages, may lead to non-coincidence of the centre lines of the various stretches of a tunnel at the meeting points.

0.3.1 Other parts of this standard are as follows:

Part II Underground excavation in rock
Part III Underground excavation in soft strata
Part IV Tunnel supports
Part V Concrete lining
Part VI Steel lining

0.4 This standard (Part I) is one of a series of Indian Standards on tunnels. Other standards published so far in the series are:

IS : 4880 (Part II)-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880 (Part III)-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4756-1968 Safety code for tunnelling work

0.5 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by deriving considerable assistance from the section ' Survey and Setting Out ' by George Hurst of the following publication:

Pequignot (CA), Ed. Tunnels and Tunnelling, Hutchinson and Co (Publishers) Ltd, London

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final values, observed or calculated, expressing the results of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off values should be the same as that of the specified values in this standard.

1. SCOPE

1.1 This standard (Part I) covers recommendations for precision survey and setting out of tunnels.

2. INITIAL SURVEYS

2.1 The alignment of a tunnel is governed by the surface conditions, rock cover available on all sides of the tunnel, etc. In case of tunnels in hydroelectric projects, the obligatory points may be the surge wells, shafts, etc. Obligatory traffic directions may decide the portal sites for tunnels in cities.

2.2 Broad alignment of tunnels should be based on detailed topographical maps or city maps prepared either by the Survey of India or the city Survey Officials or the concerned organization incharge of the tunnel. In, out of the way locations a detailed tachyometrical reconnaissance survey of the area giving both horizontal and vertical control should be conducted.

*Rules for rounding off numerical values (*revised*).

2.3 After fixing the obligatory points like portal points, shaft location, etc, on topographical maps, the run of the tunnel may be decided. The two ends of the tunnel shall be then located on ground and the stations from which driving lines can be set out shall be fixed precisely. These portal points shall be marked by concrete pillars or by concrete blocks in the ground, defined by a cross or other marks on a brass plate or plug built into the concrete or by a 25 mm to 40 mm diameter galvanized iron pipe, 30 cm long embedded in concrete with one end about 8 mm above the top of concrete surface and with a cross cut on the top of pipe (*see* Fig. 1).

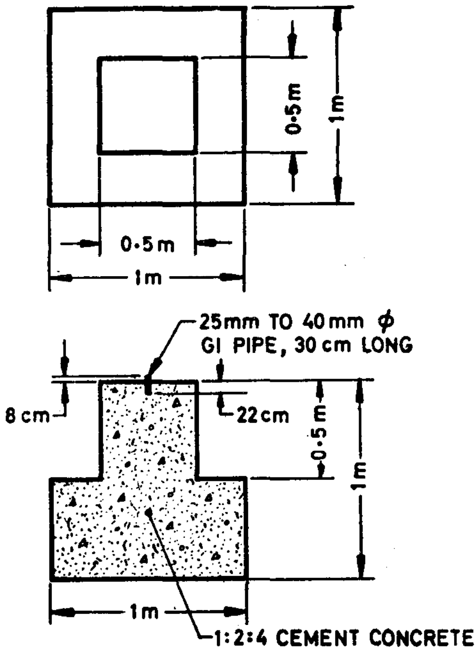


FIG. 1 CONCRETE PILLARS

3. DIRECT SETTING OUT OF THE TUNNEL CENTRE-LINE ON THE SURFACE

3.1 It is extremely rare that the contours of the ground beneath which the tunnel is situated, are sufficiently favourable to allow one extremity of the tunnel being visible from the other. Generally, the ends of the tunnels themselves are not sightable one from another. Yet a summit point can be obtained from which points in the direction of the line of

trace can be accurately determined, marked and rendered available for the alignment of the face headings, by the method of reciprocal ranging.

3.2 In open country, the approximate direction of the tunnel may be drawn on the topographical map and the direction line approximately laid out with a theodolite from one of the terminal stations (*see* X in Fig. 2), the line being extended from station to station over the intervening high ground until it reaches the other terminal station Y. The extension at each station shall be made by double-transiting the theodolite on both circle-left and circle-right, and the mean position shall be taken as the prolongation. In the first trial there may be some deviation, say, δ of the end of the extended line from the second terminal station Y. The intermediate station Z shall be then moved laterally by an amount δ' equal to $\delta \times \frac{XZ}{XY}$ and the extension processs shall be repeated until a straight line through X and Y is obtained. Pillars shall be erected at the intermediate stations and the whole process repeated, several sightings being taken at each intermediate station in both circle-left and circle-right positions. The mean of each set shall be taken as the true prolongation of the back line and over this the theodolite shall be centred for next stage of the extension. When the line passes exactly through both terminal stations the intermediate stations shall be finally marked.

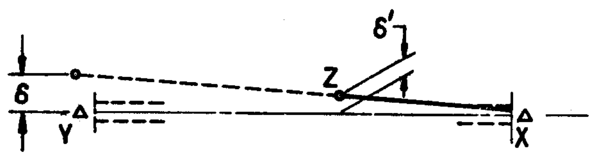


FIG. 2 SETTING OUT OF CENTRE LINE ON THE SURFACE

3.3 The method specified in **3.2** will not be possible in towns or open flat yet very woody area where an open or closed theodolite traverse shall be required between the terminal points. Stations shall be marked on metal plates set into curb-stones or similar constructions. The route chosen should include stations on or near to any intermediate points, where it is proposed to sink shafts near to or in the line of the tunnel axis. This will facilitate the final precise measurement on the ground from the traverse station to the tunnel axis.

3.4 For usual tunnelling, the accuracy for theodolite traverse shall be of the order of 1 in 10 000 with angular error of closure not exceeding $15\sqrt{N}$ seconds where N is the number of angles of a traverse and linear measurements are taken with the help of normal steel taps. However, fine accuracies can be obtained with the help of 1 second theodolites and accurate measurements by invar-subtense bar or invar taps.

4. TRIANGULATION

4.1 In mountainous country both the direct setting out of tunnel by reciprocal ranging or by a traverse survey is physically not practicable. Precise triangulation should be used in such cases. In other cases also a triangulation survey should be done to serve as a check on the direct alignment of the tunnel axis.

4.2 Triangulation is based on the principle that by measuring one side and angles of a triangle accurately; the remaining sides can be calculated by trigonometry. Fig. 3 shows a scheme, in which the base *QR* is very accurately, measured by subtense bar or hunter short base or base line measurement equipment, such as invar tapes or wires. By measuring each angle of each of the triangles in the layout accurately up to one second or less depending upon the availability of instruments the various sides may be calculated and co-ordinates carried on from one end to the other. At the other end the length between two known points *X*, *Y* as arrived at by calculations as above, shall be compared by actual measurements, made equally accurately as for base *QR*. The discrepancy between the two should be insignificant to prove the accuracy of the whole layout, field measurements and calculations.

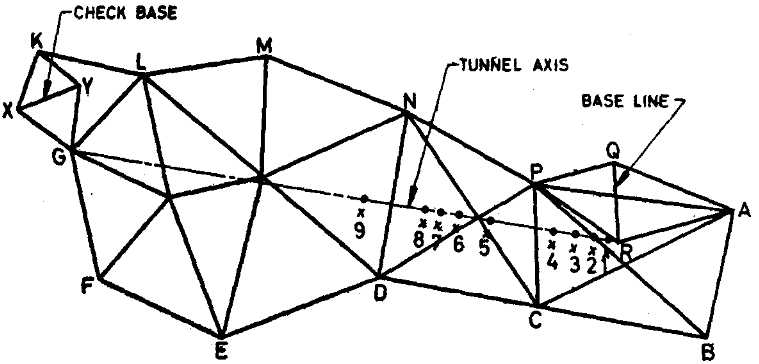


FIG. 3 TYPICAL TRIANGULATION SCHEME

4.3 If the area of a project is already covered by Survey of India triangulation, it would be possible by using the National trigonometrical stations (also called the G.T.S. stations) to obviate the time spent in measuring a base line and to reduce the amount of angular work. However, unless the surveys done by Survey of India are carried out to the tertiary stage with stations at about 3 km or so that the number of stations available may be insufficient to be of material assistance to the project.

NOTE — In such a case the initial triangulation in the area can be got done from the Survey of India, according to the importance of the scheme and cost involved. Due

regard shall, however, be paid to the nature of project. What is normally required in a localized project, is the distances as measured on the surface of earth but without the true bearings. Normally the difference between the grid bearings and true bearings is insignificant in such small areas and a network of co-ordinates with true distances and grid bearings is all that is required to be established by Survey of India.

4.4 Local triangulation network should consist of geometrically sound figures namely, triangles, quadrilaterals and occasionally even polygons and the observed angles should be suitably adjusted to conform to the requirements of such figures.

4.5 The following precautions shall be taken to avoid probable sources of error:

a) The site for measurement of base line should be approximately level, evenly sloping or gently undulating and as free as possible from obstructions in order that a line of the required length may be accurately measured without undue expenditure. The base line should be as long as possible and its length should be, preferably, 1/12 to 1/15 of the total length of the tunnels to be driven, if practicable.

b) To set up a new reference point, the most desirable way is by a single triangle with no angles less than 45°. As a check, observations for another triangle should also be made. If a single triangle with any of its angles not less than 45° cannot be obtained this limit on the angle may be reduced but the angle shall not be less than 30°. This shall, invariably, be checked with another triangle. But this triangle shall not be used for further extension of the triangulation of the system. If any of these two conditions cannot be obtained in any location a braced quadrilateral should be adopted.

c) It is advisable to have two independent sets of observations done by two independent observers using different instruments and the results calculated independently and the particular set of calculations may be taken as correct only if the final results are found to agree within acceptable limits of difference as specified in **3.4**. The same criteria should be followed while setting out the alignment along the floor of the tunnels and checking it. In all these calculations, seven figure log tables shall be used and the calculations for angles shall be based on tables giving values up to one second of an angle.

d) For the calculation of angles, computation forms shall be used (a typical form is given in Appendix A).

e) For base line measurements for tunnels of smaller lengths say about 5 to 6 km, ordinary but calibrated steel tapes may be used. For longer tunnels and complicated layouts, invar tapes or wires shall be used.

f) While arriving at the true base line length, the following corrections shall be applied. At other places where the country is hilly repeated measurements in small stretch by invar-subtense bar may also be made (*see* Fig. 4):

1) Correction for absolute length,
2) Correction for temperature,
3) Correction for tension or pull,
4) Correction for sag,
5) Correction for slope or vertical alignment,
6) Correction for horizontal alignment, and
7) Reduction to sea level.

NOTE — A correction is said to be plus or positive when the uncorrected length is to be increased, and minus or negative when it is to be decreased in order to obtain the true length. It may be noted that each section of the base line is separately corrected.

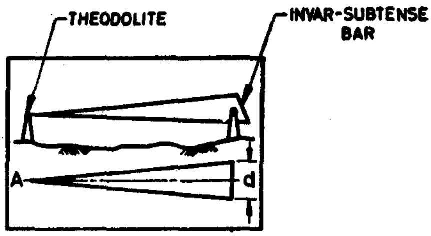


FIG. 4 USE OF INVAR-SUBTENSE BAR

4.6 Theodolites — One second or less glass arc theodolites are essential to get high accuracies in tunnelling (*see* IS : 2976-1964*). Before commencing any triangulation, the theodolite shall be tested for its permanent adjustments.

4.6.1 For measurement of angles the following procedure is recommended:

a) Set the circle and micrometer to read approximately zero on station A and take a round of readings moving in a clockwise direction. On each stations B, C, D, E and A the tangent screw shall be operated to give only a clockwise motion. On closing the single round on to station A, any permissible departure of the reading from the initial reading shall be distributed among the various angles.
b) Reverse the telescope on to the opposite face and repeat the observations, but proceeding in a counter-clockwise direction, thus completing a double round.
c) Operations (a) and (b) may be repeated say five times with initial settings at approximately 60°, 120°, 180°, 240° and 300°;

*Specification for optical theodolite.

in practice a surveyor should verify in the field, for his particular instrument, how many repetitions are necessary to obtain the required degree of accuracy.

d) After each double round the theodolite shall be re-levelled, if necessary. In mountainous country involving very steep sights, the levelling shall be carried out with reference to the most sensitive bubble, which is generally the one on the top of vertical vernier arm. The circles are best illuminated by the built-in electric lighting and care shall be taken to avoid the springs of the tangent screws becoming fully compressed or extended. For each sight, the mean of four or five micro-readings of the circle shall be obtained.

4.7 Target — Target may be, normally, a steel ranging rod inserted in a concrete block (Fig. 5) and suitably guyed, to maintain the vertical position. The design of the target merits careful study having regard to the equality and direction of the light, the clarity of the atmosphere, the type of background, and the length of sight. The best weather for surface angling is calm and moderately cloudy weather. On hot days the shimmering of the image will usually prevent angling between 1 000 h to 1 400 h. For long distances white against black shows up best and *vice versa* for short distances.

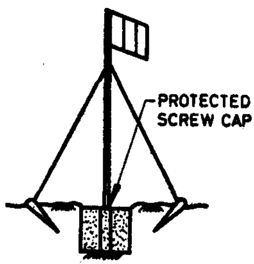


FIG. 5 TYPICAL TARGET

4.8 Degree of Accuracy in a Triangulation

4.8.1 For triangulation for small length tunnels say of 5 km or so, a minimum accuracy of 1 in 10 000 is essential though for longer tunnels much higher accuracy as in case of secondary triangulation is essential. For small localized areas and even in area of say 65 km^2, that is, even with tunnel length of 15 to 20 km error due to spherical excess is almost negligible (being of the order of 1 second for every 200 km^2). Average triangle closure for a survey of 1 in 10 000 accuracy is of the order of 5 seconds and shall not exceed 10 seconds.

NOTE — The accuracy with which approaching tunnels meet reflects the accuracy of the survey. Not only must the tunnels meet with little lateral error, but the approaching lines should make no angle with each other, though errors of a few centimetres at the holing may be distributed over a few hundred metres on either side.

4.8.2 In a triangulation network error should be propagated in the following two ways:

a) Error in the measurement of the base-line, which imparts a scale error to the whole work. This, however, has no effect on a holing, provided that no other linear measurements are involved in the project. In any case the effect is small.

b) Error in measurement of angles giving rise to error in the computed lengths of the triangle sides, and to lateral deviation of the sides from their true direction.

4.8.2.1 Utmost care shall be taken while observing the various angles and while setting out tunnel by angles. This is further illustrated in Fig. 6 and Fig. 7. Starting at the portal *A* (*see* Fig. 7), the line is run into a point *B*, where an angle *a* is turned and the line run to *C*. If there is an error in chaining, then the point will be established at B_1. But the new line B_1C_1 will be parallel to the true line *BC*. However, if an error is made in line when starting at the portal, it would give a point B_2. If the angle is then turned on this point, the new line B_2C_2 would constantly digress from the true line so much that at a distance of about 300 m the error would be 11 times that at point *B*.

4.8.3 Having observed the angles, with utmost accuracy, though the method of least squares should be adopted for adjustment of triangulation, it is sufficient to use the following methods if the angular measurements are carefully done:

a) For a triangle, the sum of all angles is 180°:

b) For a quadrilateral, (1) the sum of opposite pairs of angles is equal, (2) the sum of the circumferential angles is equal to 360°, (3) the sum of the log-sines of the left-hand angles is equal to the sum of the log-sines of the right-hand angles, looking towards the centre of the figure.

c) For other polygons:

   1) the sum of angles of each triangle is 180°,

   2) the sum of central or hub angles is 360°, and

   3) the log-sine relation is the same as for a quadrilateral.

NOTE — It is assumed that all the angles have been measured with equal care and any adjustment is, therefore, made equal on the angles concerned. It should also be emphasized that the adjustment does not necessarily make the values of the angles correct; it does, however, facilitate checking the computations when calculating the co-ordinates of stations, since any computations round a closed adjusted circuit, say *A, B, C, D, E, F, G, K* and back through *L, M, N, P, Q* to *A* (Fig. 3) should close exactly within the limits of error set by the mathematical tables employed.

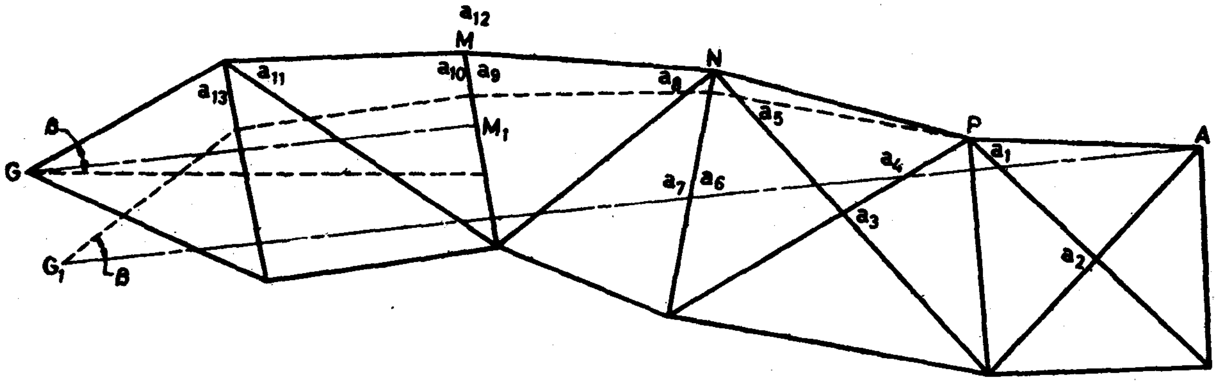


Fig. 6 Propagation of Lateral Error in Triangulation Due to Angular Error

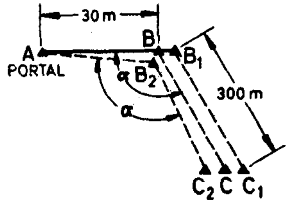


FIG. 7 EFFECTS OF CUMULATIVE ERRORS IN SURVEYING

5. LEVELLING

5.1 Instruments — For normal tunnelling a level shall be such as to be capable of giving an accuracy of $\pm$ 2 mm/km of levelling in normal country.

5.2 Precautions — Before commencing and after completing any levelling the level shall be checked for its permanent adjustment. The following precautions shall be persistently taken to avoid the many sources of error:

a) Careful focusing of diaphragm lines and staff and elimination of parallex;

b) The use of staves which are engine-divided preferably, not of sopwith staff arranged in three telescopic lengths, nor more than 3 m in length;

c) The use of a micrometer device for reading fractional parts of the 0·01 division which is helpful but not essential;

d) Limiting the length of sights to a maximum of 50 m (preferably less) and the equalization in length of the backsights and foresights;

e) The use of reliable foot-plates as turning points, where necessary;

f) Care in ensuring that the bubble is in its mid-position at the time the reading of the staff is taken;

g) Careful holding of the staff in a vertical position and avoidance of windy weather which makes this impossible;

h) Levelling within the period 1 000 h to 1 600 h in which refraction is the steadiest. At the same time this is the period when heat-shimmer is apt to be troublesome. Cool but bright weather with gentle wind is the best;

j) Protecting of the instrument by an umbrella from the direct rays of the sun;

k) Choosing such a route which permits equalization of lengths of backsights and foresights; and

m) The level survey shall be closed, preferably by repeating the levelling in the opposite direction by the same route and within a short time.

5.3 Any permissible error shall be distributed among the several stations in the proportion to the distance of the station from the starting point. With attention to these details there should be little difficulty in establishing the relative levels of the portals and of any intermediate stations on the surface of the tunnel section. At each of these stations stable bench marks shall be established.

5.4 Reciprocal Levelling — At many tunnel sites in steep mountainous country where there are precipitous slopes, normal levelling with staves is physically impossible. In such situations it is necessary to use reciprocal levelling, done by means of two simultaneous theodolite observations on two respective triangulation stations, projected distance between which is already accurately calculated.

5.4.1 *Reciprocal Observations* — In this method the vertical angle to each station is observed from the other station, and the refraction effect is assumed to be the same at each station. In order to completely eliminate the refraction effect, simultaneous observations should be taken whenever possible. It is not, however, usually possible to measure the vertical angles simultaneously. They should, therefore, be measured at the time when the refraction effect is minimum and on different days. Since refraction is less variable between 1 000 h to 1 500 h the vertical angles should be measured during these hours. The results obtained by this method are more accurate than those obtained by the method given in **5.4**. This method is explained below (*see also* Fig. 8):

Let A and C = the stations whose difference in elevation is required.

From Fig. 8:

d = the horizontal distance between A and C,

AB = the level line passing through A,

CD = the level line passing through C,

AF = the horizontal line at A (tangential to AB),

CE = the horizontal line at C (tangential to CD),

AaC = the curved line of sight,

AA' = the line tangential to AaC at A,

CC' = the line tangential to AaC at C,

$\angle A'AF$ = the angle of elevation observed at $A = \alpha$,

$\angle C'CE$ = the angle of depression observed at $C = \beta$,

$\angle A'AC$ = the angle of refraction at A,

$\angle C'CA$ = the angle of refraction at C,

$\angle APC$ = the central angle (θ),

H = the difference of elevation of A and C,

$$H = d.\frac{\sin\frac{\alpha+\beta}{2}}{\cos\frac{\alpha+\beta}{2}+\frac{\theta}{2}}$$

when the distance d is not very great, $\frac{\theta}{2}$, being very small, may be neglected. Then $H = d \tan\frac{\alpha+\beta}{2}$.

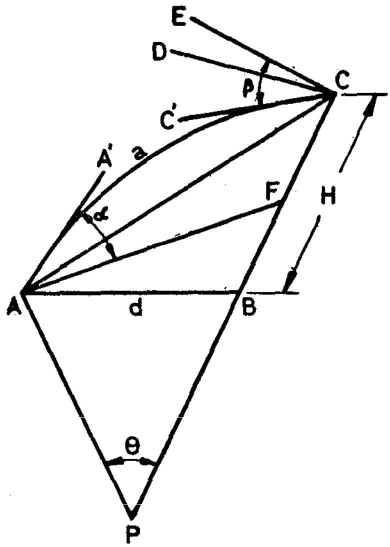


FIG. 8 RECIPROCAL LEVELLING

5.5 Plumb-Line Observations — In mountainous countries at high altitudes, the level line gets attracted towards high mountain masses. Hence, to establish the effect of such attraction due to such mountain country at high altitude out of plumb observations have got to be made and necessary corrections applied.

5.6 Automatic Level — These levels are of great help where the levelling is to be done near vibrating machines and also in tunnels where

dumpers and other machinery is always playing. It ensures high accuracy and reduces the time of levelling.

NOTE — Whenever feasible use of high accuracy levels is recommended.

6. SETTING OUT INSIDE TUNNELS

6.1 Having finalized the co-ordinates of various portals of tunnels, etc by triangulation and also the relative levels of various portals, setting out of tunnels may be started from the various portals (*see* Fig. 9).

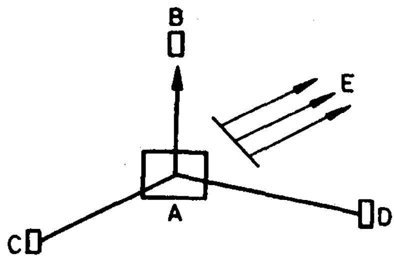


FIG. 9 SETTING OUT OF CENTRELINE OF TUNNEL

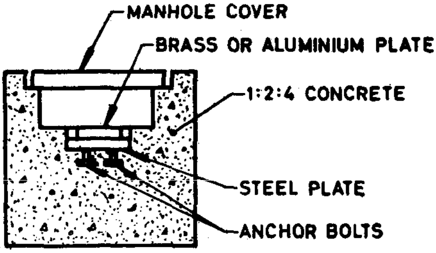
This may be done by backsighting on pillars aligned and constructed as far away as practicable on the extended centre lines such as pillar *C* and then transiting or by sighting distant pillar like *B* and turning the previously calculated angle *BAE*.

However, in the later case a second check by turning angle with reference to a certain pillar *D* is always essential. It is also essential to sight as distant reference pillars as possible, to get test accuracy.

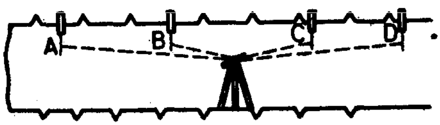
NOTE — The latest technique for alignment of tunnels is by gyro-theodolite or by laser beam.

6.2 Reference Points — In the tunnel reference points shall be constructed at about every 300 m or so. These reference points or marks may be constructed on the roof of tunnels (*see* Fig. 10), or slightly below the invert of the tunnel (*see* Fig. 10A). The pillars at the invert of tunnel shall be cast in concrete with preferably non-rusting plates fixed flush with top of concrete. These plates shall be properly protected.

6.3 Repeated observations with circle-left and circle-right shall be made to finally mark the correct alignment point on each of the reference plates. Levels of these reference marks shall be determined accurately by taking necessary precautions as given in **5.2**. All the work of finally fixing the exact alignment marks in the tunnel should, preferably, be done on holidays when the other work in tunnels is suspended or at night time by stopping vehicular traffic in the tunnels to minimize refraction errors and to achieve utmost accuracy.



10A FOR INVERT



10B FOR ROOF

FIG. 10 TYPICAL REFERENCE MARKS

6.3.1 Centre line and reference level line shall be marked on the face of tunnels for every blast to minimize errors.

6.3.2 Reference springing lines or belt lines of plaster patches at a certain convenient height above the invert, and reference chainage lines shall be marked on the sides of tunnel at about every 15 metres or so with reference to the main reference centre plates and bench marks. This will facilitate quick work on taking cross sections and other measurements in tunnel.

7. SETTING OUT STEEPLY INCLINED SHAFTS

7.1 The method for giving alignment of inclined tunnels is similar to that adopted in case of horizontal tunnels. The horizontal alignment (as in plan) of the inclined tunnel shall be fixed from upper/lower apex point. The vertical angle of its correct value of slope shall be then adjusted on the theodolite and the sloping ray marked on the heading. Levelling of both horizontal circles and vertical circles of the theodolite shall be done perfectly and while the alignment for level is being given by vertical angle of the precision theodolite, it shall be verified from time to time that the horizontal circle bubble is in the centre or is in perfect adjustment. Knowing the level of the collimation and thus the height of the collimation above the designed invert at the place of the instrument, the designed level of invert at the heading can be marked by tape. Distances shall be marked by calibrated steel tapes or with the help of invar-subtense bar.

Knowing the alignment and the invert level the excavation section at the heading can be plotted. Use of diagonal eye-piece attachment to the theodolite is of great help in the alignment of steeply inclined shafts and is recommended.

8. TRANSFERRING OF ALIGNMENT THROUGH SHAFTS

8.1 In very long tunnels or where great speed is required, work may be carried out from intermediate positions.

8.1.1 When the tunnel axis is aligned on the surface, intermediate stations are automatically aligned at the required positions. Where, however, a triangulation scheme is necessary the co-ordinates of the exact position of the intermediate stations shall be computed. The lengths and bearings of the lines connecting them to the nearest triangulation station shall be such that they can be precisely measured.

8.2 Transfer of alignment through drafts may be done by any one of the following methods:

a) Co-planing by hanging two or more plumb-lines down the shaft (*see* **8.3**),

b) Sighting directly from edge of shaft where shaft diameter to depth ratio is high,

c) By means of objective pentoprism method, and

d) By means of optical plumet and gyro.

8.3 Co-planing may be conveniently done by hanging two or more plumb-lines down the shaft and determining the bearing of the plumb-plane so formed by connecting it to the surface survey. It may be assumed that the bearing of the plumb-plane under ground is the same as at the surface, so that this becomes the starting direction for the underground survey work.

8.3.1 Two plumb lines shall be suspended in the vertical shaft as far apart as possible. They shall be of fine steel wire and each carrying a symmetrical weight of 35 kg or more. It is advisable to strain the wires up to half their breaking strength. The bobs should have projecting vanes to reduce rotation and oscillation of the wire and should be contained in a canister with a hood, which shields the bob and helps to reduce random oscillations set up by air currents or by water dropping down the shaft. It is also advisable to fill the canister with water or light oil to reduce the vibrations. In very deep shafts it may be difficult entirely to remove these oscillations; in such cases heavy bobs up to 135 kg in weight are recommended. However, their use require larger diameter wires, which make accurate bisection of the wires more difficult. Geared winches should be used to control such heavy weights. The true vertical position

shall be determined either by fixing scales behind the wires and observing through the theodolite the limits of the oscillations of the bob a large number of times, and then computing the mean position; or, preferably, if the oscillations are small, by reading against a fine scale fitted in the eyepiece of the telescope. The wires shall be then clamped in the mid position by some clamping device.

8.3.1.1 A light pilot weight should be used for lowering and raising the wire in the shaft, and the heavier bob put on and taken off at the shaft bottom. It is advisable to choose a calm day on the surface unless the wire can be suitably shielded. It shall be ensured that the wires are suspended freely.

NOTE — For dropping down the wire a split washer is favoured but not certain method. A useful, but still not infallible, check is to measure carefully and compare the lengths of the wire interval both at the surface and underground. In doubtful cases it may be advisable to hang a third wire to form the three sides of a triangle.

8.3.1.2 The level shall be transferred from the vertical shaft by means of steel bands; chain or invar wires, on a calm, non-windy day. Repeated measurements shall be made to ensure higher accuracy.

9. CURVES

9.1 While setting out curves, till the tunnel proceeds for some safe length beyond the first tangent point, alignment for each blast may be given by the method of offsets from the tangent. Once the tangent point is fixed in the tunnel, the use of deflection angle method is recommended for accuracy. Wherever it is possible, it is preferable to fix apex point inside the tunnel even at the expense of some extra excavation since that will perfectly ensure high accuracy beyond the curve.

10. ADJUSTMENTS AT MEETING POINTS OF TUNNELS

10.1 If the error is less, say 25 to 50 mm, it should be adjusted in the erection of shuttering for concreting itself. If the error is of higher order, *S* curves of very large radii should be introduced near junction points.

11. CARE OF INSTRUMENTS

11.1 All optical instruments, such as theodolites, levels, etc shall be checked for permanent adjustment as often as possible. These instruments shall also be got overhauled, tested and repaired when necessary, every year during the low-work period. Optical prisms shall be often cleaned of fungus growth, which is normal source of trouble especially in coastal regions. In high humidity and heavy monsoon areas, the theodolites, levels, etc shall be kept in steel cupboards and the room should be provided with electric heaters to keep the instruments in good condition. Calibration of tapes, invar wires shall be got done. Dehumidifying chemicals, such as silicagel shall be kept in instrument box and maintained in proper conditions by heating it often.

APPENDIX A

[*Clause* 4.5, Item (d)]

CALCULATION FORMS A AND B

Calculation Form A

PRECISION SURVEY DATE

Computation of log sides of triangulation for tunnel

Station of Intersected Point	Observed Angle	△ error	Corrected Angle	Log Sines	Log Sides	See No.	Side
A							BC
B							CA
C							AB
△ No... 1 Total				K			

In grid units: (i) Log side = K + log sin (opposite angle), (ii) K = log AB + log cosec C, (iii) Enter here log cosec C (= 0 − log sin C).

Computed by Date Checked by Date

Calculation Form B

PRECISION SURVEY DATE

Computation of Co-ordinates given Grid Distance and Grid Bearing

NOTE — Grid bearings are measured from North.

1.	Ref No.	Station C
2.	Station A	Station B
3.	Bearing at A of B	Bearing at B of A
4.	Corrected angle BAC*	Corrected angle ABC*
5.	Sum = Bearing at A of C = β	Sum = Bearing at B of C = β
6.	Log sin β	Log sin β
7.	Log AC*	Log BC*
8.	Sum = Log δ E	Sum = Log δ E
9.	Log cos β (β from line 5)	Log cos β (β from line 5)
10.	Log AC (line 7)	Log BC (line 7)
11.	Sum = Log δ N	Sum = log δ N
12.	Easting of A	Easting of B
13.	δ E†	δ E†
14.	Sum = Easting of C	
15.	Northing of A	Northing of B
16.	δ N‡	δ N‡
17.	Sum = Northing of C	

*From calculation form No. A.

†Positive if β is between 0° and 180° : otherwise negative.

‡Negative if β is between 90° and 270° : otherwise positive.

Computed by Date Checked by Date

AMENDMENT NO. 2 MARCH 2003
TO
IS 5878 (PART 1) : 1971 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART 1 PRECISION SURVEY AND SETTING OUT

(*Page* 5, *clause* **2.3**, *line* 8) — Substitute '8 cm' *for* '8 mm'.

(WRD 14)

Reprography Unit, BIS, New Delhi, India

IS 5878-2-2 (1971): Code of Practice for Construction of Tunnels, Part II: Underground Excavation in Rock, Section 2: Ventilation, Lighting, Mucking and Dewatering [WRD 14: Water Conductor Systems]

BLANK PAGE

IS : 5878 (Part II/Sec 2) - 1971
(Reaffirmed 1990)

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART II UNDERGROUND EXCAVATION IN ROCK

Section 2 Ventilation, Lighting, Mucking and Dewatering

(Fourth Reprint SEPTEMBER 1994)

UDC 624.191.94

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3 September 1971

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART II UNDERGROUND EXCAVATION IN ROCK

Section 2 Ventilation, Lighting, Mucking and Dewatering

Water Conductor Systems Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE
Ramalayam, Pedder Road, Bombay-26

Members	*Representing*
SHRI N. M. CHAKRAVORTY	Damodar Valley Corporation, Dhanbad
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhara Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (CIVIL AND INVESTIGATION CIRCLE) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
DEPUTY DIRECTOR (DAMS I)	Central Water & Power Commission, New Delhi
DIRECTOR	Irrigation & Power Research Institute, Amritsar
DR GAJINDER SINGH (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong
SHRI O. P. DUTTA	Beas Project, Nangal Township
SHRI J. S. SINGHOTA (*Alternate*)	
SHRI R. G. GANDHI	The Hindustan Construction Co Ltd, Bombay
SHRI M. S. DEWAN (*Alternate*)	
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI B. S. KAPRE	Irrigation & Power Department, Goverment of Maharashtra
SHRI R. S. KALE (*Alternate*)	
SHRI V. S. KRISHNASWAMY	Geological Survey of India, Calcutta
SHRI K. S. S. MURTHY	Ministry of Irrigation & Power
SHRI Y. G. PATEL	Patel Engineering Co Ltd, Bombay
SHRI C. K. CHOKSHI (*Alternate*)	
SHRI P. B. PATIL	Gammon India Private Ltd, Bombay
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI G. S. SHIVANNA	Public Works & Electricity Department, Government of Mysore
SHRI S. G. BALAKUNDRY (*Alternate*)	

(*Continued on page* 2)

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

(*Continued from page* 1)

Members	*Representing*
SECRETARY	Central Board of Irrigation & Power, New Delhi
SHRI J. E. VAZ	Public Works Department, Government of Tamil Nadu
SHRI J. WALTER (*Alternate*)	
SHRI D. AJITHA SIMHA, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

SHRI BIMLESH KUMAR

Assistant Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra
Members	
SHRI R. S. KALE (*Alternate* to Shri B. S. Kapre)	
SHRI C. K. CHOKSHI	Patel Engineering Co Ltd, Bombay
DEPUTY DIRECTOR (DAMS I)	Central Water & Power Commission, New Delhi
SHRI M. S. DEWAN	The Hindustan Construction Co Ltd, Bombay
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI K. SHAMA RAO	Kerala State Electricity Board, Trivandrum
SHRI A. S. NARAYANAN (*Alternate*)	
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh

AMENDMENT NO. 1 MARCH 1977
TO
IS:5878(Part II/Sec 2)-1971 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS
PART II UNDERGROUND EXCAVATION IN ROCK
Section 2 Ventilation, Lighting, Mucking and Dewatering

Alteration

(First cover page, pages 1 and 3, title) - Substitute the following for the existing title:

'*Indian Standard*
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART II UNDERGROUND EXCAVATION IN ROCK

Section 2 Ventilation, Lighting, Mucking and Dewatering'

(BDC 58)

Reprography Unit, BIS, New Delhi, India

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART II UNDERGROUND EXCAVATION IN ROCK

Section 2 Ventilation, Lighting, Mucking and Dewatering

0. FOREWORD

0.1 This Indian Standard (Part II/Section 2) was adopted by the Indian Standards Institution on 15 March 1971, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The construction of tunnels involves a large number of problems because of the great longitudinal extent of the work and many kinds of conditions are encountered which for maximum economy should be treated differently. In view of this it has been appreciated that it would be futile to prepare a rigid set of rules or procedures which can be enforced without leaving any latitude for the exercise of discretion by the site engineer. The aim of this standard is to summarize the well known and proved principles and to describe the commonly used procedures and techniques for providing guidelines which would permit the site engineer to use his discretion. This section deals with the requirements for ventilation and lighting and procedures of mucking and dewatering for excavation of tunnels in rock. The Indian Standard Code of Practice for Construction of Tunnels (IS : 5878) is being published in parts and Part II in sections.

0.3 Section 1 of this part covers drilling and blasting, and section 3 tunnelling method for steeply inclined tunnels, shafts and underground power houses.

0.4 Other parts of this standard are as follows:

Part I Precision survey and setting out
Part III Underground excavation in soft strata
Part IV Tunnel supports
Part V Concrete lining
Part VI Steel lining
Part VII Grouting

0.5 This standard is one of a series of Indian Standards on tunnels.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

---

1. SCOPE

1.1 This standard (Part II/Section 2) deals with ventilation, lighting, mucking and dewatering for excavation of tunnels.

2. SAFETY REQUIREMENTS

2.1 Adequate safety requirements, in regard to ventilation, lighting, mucking and dewatering, shall be taken as specified in IS : 4756-1968†.

3. VENTILATION

3.1 Necessity—The purpose of ventilation in tunnels is to make the working space safe for workers by keeping the air fresh and respirable, free from harmful obnoxious gases and dust. Ventilation also serves the purpose of bringing down high temperatures (especially at the working face) due to diesel engines working inside the tunnel.

3.2 Mechanical ventilation shall be adopted to force the air in or out from the working-face through ventilation ducts.

3.3 Minimum requirements of purity of air, dust control and volume of air shall be in accordance with IS : 4756-1968†.

3.4 Methods—The following three methods are normally used for mechanical ventilation:

a) Blowing in fresh air by ducts to the face of tunnel,

b) Exhausting foul air by ducts from the face of tunnel so that fresh air is supplied *via* the tunnel itself, and

c) Combination of blowing in and exhaust system.

3.4.1 The method of ventilation by blowing in fresh air is a positive means of supplying fresh air to the working face. However, the location of the air intake shall not be such as would short circuit foul air coming from the tunnel. It is the most convenient method of ventilation during drilling

*Rules for rounding off numerical values (*revised*).
†Safety code for tunnelling work.

and mucking operations, when persons working at face require fresh air. However, this method has a disadvantage that the foul air while being expelled through the tunnel, itself makes the approach to the working face from the portal rather unhealthy with poor visibility.

3.4.2 The method of ventilation by exhausting foul air is useful after blasting when it is desirous that blasted fumes should be removed expeditiously without being diffused along the whole length of tunnel. The location of the exhaust shall be such as not to pollute the air going into the tunnel. However, this method has a disadvantage that the fresh air while travelling along the length of tunnel absorbs heat moisture and foul gases of the hauling equipment resulting in an unpleasant working condition at face.

3.4.3 In the method of simultaneous exhausting and blowing, two systems of piping are required with their own independent mechanical blowers. The exhaust system will have a larger capacity, whereas the blowing system may have smaller diameter duct, sufficient for providing enough fresh air to workmen on face of tunnel. However, this method requires complete duplication of ventilation system and would be impracticable unless the driven tunnel is very long.

3.4.3.1 In practice the combined system of ventilation may be achieved by exhausting the gases after blasting and for all other operation using blowing in system. This may be achieved by providing reversible ventilation fans, whereby with the same installation of ducts and blowers the exhausting and blowing in air may be achieved.

3.5 Ducts—Ventilation ducts may be either of fabric or of metal.

3.5.1 Fabric ventilation ducts made out of high resistant nylon can only be used for blowing system as during suction the fabric would collapse.

3.5.2 Metal ducts shall conform to IS : 655-1963*.

3.5.3 Duct line may be laid either on the floor or hung from the side wall excavation depending on convenience and other economic aspects of ventilation. However, care shall be exercised to see that all the joints of duct line are air-tight to avoid losses due to leakage.

3.6 Ventilation Shafts—These may be provided at the intermediate section of a tunnel or at the extreme end of the underground work, say power house, after studying the economics of the same.

3.7 Fans — Ventilation fans can be of numerous types, such as non-reversible or reversible, externally driven or internally driven type. However, reversible type axial blowers with fan fitted directly on totally enclosed electric motor is recommended for ventilation of tunnels. It is a normal practice to fit two such units in one shell to increase the total output.

*Specification for metal air ducts (*revised*).

3.7.1 In the use of ventilation system the pressure under which the air is to be pumped into the tunnel may be mentioned. The diameter of pipe shall be fixed after taking into account the frictional resistance of air flow through the pipes and other relevant factors. Some length of the air duct near the working face should be kept flexible. For longer length of tunnel, addition of boosters at a suitable place may be necessary. For some length from the portal no elaborate ventilation system is necessary for excavation of tunnel.

4. LIGHTING

4.1 Adequate lighting shall be provided at the face and at any other point where work is in progress, at equipment installations, such as pumps, fans and transformers. A minimum illumination of 100 lux shall be provided at tunnel and shaft headings during drilling, mucking and sealing. When mucking is done by tipping wagons, running on trolley tracks, a minimum of 50 lux shall be provided for efficient and safe working. Along the length of the tunnel also adequate lighting shall be provided.

4.1.1 Any obstructions, such as jumbo, form work, etc, inside the tunnel shall be well lighted to avoid accidents when hauling units are moving.

4.1.2 Lighting at the working face shall be profuse. However, no single light shall be so powerful as to cause temporary blinding effect when looked at.

4.2 Voltage of supply line may be reduced in the tunnel from 230 V to 110 V for lighting purposes, where practicable. For motors of 440 V waterproof cables shall be laid in tunnels.

4.3 Incandescent lamps should be fixed in the centre of the roof of tunnel. In case the lamps are to be fixed on sides of tunnel, they shall be as high as possible and well above the ventilation ducts, so that the shadow of the duct is not formed on the road surface.

4.4 The electric circuits of the lighting in tunnel shall be divided into number of independent circuits with their isolators and fuse boxes separate. With the separation of the circuits, the repair works on the electric lighting system can be easily done by switching off the desired circuit while the other circuits are still in operation.

4.5 In addition to the fixed lighting system, all hauling equipment shall have their own lighting system. These lights not only give indication to the personnel in the tunnel of the approach of the hauling equipment but also permit them to negotiate the tunnel without any danger in case of emergencies when the fixed light systems are turned out.

4.6 In addition to the normal lighting, provision of flood lights shall be made at suitable intervals for detailed inspection for any particular length or spot.

5. MUCKING

5.1 The hauling equipment may be classified into the following major categories:

a) Hauling on rails,

b) Hauling on pneumatic tyres, and

c) Other equipment like conveyors.

5.1.1 The choice of the equipment will, however, depend on numerous factors, such as shape, size and slope of tunnel, type of loading equipment available and the overall economy on the construction of the particular job.

NOTE 1 — The hauling system on rails is the oldest system used. Its advantage is that once the rails are laid, the hauling equipment, that is, wagons can be pulled on the track by locomotives requiring lesser horse power. It is, in fact, the cheapest mode of hauling. However, it has one basic disadvantage, that is, it has no flexibility of movement as the wagons have to move on fixed rail system only. This system can be conveniently used where the hauling grade is either fairly level or where the grade is very steep. In the former case, locomotives are used, while in the latter case haulage winches are used. Suitable arrangements for car changes, points and crossings, etc, would, however, be required in this case.

NOTE 2 — With large diameter tunnels, the haulage equipment on pneumatic tyres such as dumpers are best suited for the job. In view of restriction of space, the dumpers are of reversible type, or articulated type, so that the equipment does not have to take any turning inside the tunnel. Various models of reversible type and articulated type dumpers suited for tunnels are in the market, however, choice of the dumper will also depend on the loading equipment used inside the tunnel.

5.2 Capacities of the various loading equipment may be fixed depending upon the following:

a) Combination of units and time cycle;

b) Factors influencing the loading capacity, such as type of material excavated, working conditions, efficiency of the operator, condition of the machine, swing-angle of the machine, etc;

c) Struck capacity and heaped capacity;

d) Rock bodies for trucks and dumpers impact factors, etc; and

e) Belt conveyors and the type of loaders that go with belt conveyors.

5.3 Loading equipment in tunnel may be subdivided into many types depending on the mode of travel, type of loading mechanism or mode of power.

5.3.1 On the basis of its mode of travel the type of loading equipment may be classified as:

a) rail mounted,

b) crawler mounted, and

c) pneumatic-tyre mounted.

5.3.2 On the basis of its loading mechanism, the types of loading equipment may be classifiad as:

a) front end loaders,
b) overhead rocker shovels, and
c) short boom shovels.

5.3.3 On the basis of its motive power, the loading equipment may be classified as:

a) pneumatically driven,
b) diesel driven, and
c) electric driven.

5.3.3.1 In all conditions the hauling equipment and the loading equipment may be either driven by diesel, electricity or compressed air.

5.3.4 Diesel power is predominantly used for two main reasons, namely, cheapness in operation and absence of carbon monoxide in the exhaust. While diesels generate no carbon monoxide, their fumes are nauseating to breath ; therefore, a tunnel has to be well ventilated, if diesel locomotives are used. Petrol driven engines shall not be used in any case as prime mover in any underground works, as they generate carbon monoxide.

NOTE — Now electric driven loaders as well as locos including those driven by batteries are available. When electric power is used for loading and traction, tunnels remain much cleaner.

5.4 In small size tunnels and in shafts manual loading may be resorted to. For final cleaning after every blast also manual loading should be used.

5.5 The muck shall be dumped and spread evenly in the dump areas.

6. DEWATERING

6.1 Water that accumulates in a tunnel shall be effectively removed either by gravity flow or by pumping depending on conditions and circumstances met with.

6.2 When the tunnels are driven up grade with sufficient slope, the water may be removed from the tunnel through drains normally excavated on the sides of tunnel.

6.3 Extra quantity beyond the payline shall not be specifically excavated for forming drains. Usually the removal of bottom excavated muck to form drain is sufficient for the purpose. The position of the drain will solely depend on site conditions and the type of hauling equipment, the drains shall be placed on the side only, so that the road way can have proper camber.

6.4 Where the tunnel is being driven on flat gradient or downward gradient, the water accumulated shall be pumped out. Depending on the length of the tunnel and the gradient driven, the pumping may be either made in a single stage or in multi stage with balancing suction tank for each stage. The choice of number of pumping stages will depend on economy based on numerous factors.

6.4.1 However, such balancing suction tanks shall be situated at heavy leakage points. With this arrangement, the leakage water accumulated locally should be pumped or fed by gravity, if possible, into balancing tanks from where the water may be pumped through the main multi stage pumping system.

6.5 The pumping equipment required for dewatering shall be of the type which is non-clogging as the water pumped is heavily charged with dust particles, especially the drilling dust.

6.6 The following two main types of pumps are normally used for tunnel dewatering:

a) Centrifugal pumps with open impellers (non-clogging type), and

b) Pneumatic sludge pumps.

6.6.1 The motive power for centrifugal pumps may be either electrical or pneumatic motors. Diesel motive power is not preferable due to fumes and consequent extra load on the ventilation system.

6.6.2 The centrifugal pumps may be of various types, such as suction type or submersible, that is, with positive suction and with the prime mover also submersible without being damaged by water.

6.6.3 All dewatering at the working face of the tunnel shall be carried out by means of pumps driven by pneumatic motors. The electric motors may give out strong leakage currents which is hazardous at face where electric shct firing is resorted to.

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones : 331 01 31 Telegrams : Manaksanstha

331 13 75 (Common to all Offices)

Regional Offices :		*Telephone*
Central	: Manak Bhavan, 9, Bahadur Shah Zafar Marg NEW DELHI 110002	331 01 31 331 13 75
* Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	37 86 62
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43
Southern	: C.I.T. Campus, IV Cross Road, MADRAS 600113	41 29 16
† Western	: Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95

Branch Offices :

'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48
‡ Peenya Industrial Area, 1st Stage, Bangalore-Tumkur Road, BANGALORE 560058	39 49 55
Gangotri Complex, 5th Floor, Bhadbhada Road, T.T. Nagar, BHOPAL 462003	55 40 21
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
Kalai Kathir Building, 6/48-A Avanasi Road, COIMBATORE 641037	2 67 05
Quality Marking Centre, N.H. IV, N.I.T., FARIDABAD 121001	—
Savitri Complex, 116 G. T. Road, GHAZIABAD 201001	8-71 19 96
53/5 Ward No. 29, R.G. Barua Road, 5th By-lane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg, (Nampally Station Road) HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76
Plot No. A-9, House No. 561/63, Sindhu Nagar, Kanpur Road, LUCKNOW 226005	5 55 07
Patliputra Industrial Estate, PATNA 800013	6 23 05
District Industries Centre Complex, Bagh-e-Ali Maidan, SRINAGAR 190011	—
T. C. No. 14/1421, University P. O., Palayam, THIRUVANANTHAPURAM 695034	6 21 04

Inspection Offices (With Sale Point) :

Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	52 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, CALCUTTA	27 68 00
† Sales Office is at Novelty Chambers, Grant Road, BOMBAY	89 65 28
‡ Sales Office is at Unity Building, Narasimharaja Square, BANGALORE	22 39 71

Reprography Unit, BIS, New Delhi, India

IS 5878-3 (1972): Code of Practice for Construction of Tunnels Conveying Water, Part III: Underground Excavation in Soft Strata [WRD 14: Water Conductor Systems]

BLANK PAGE

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART III UNDERGROUND EXCAVATION IN SOFT STRATA

(Third Reprint APRIL 1990)

UDC 624.191.2:624.133

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 5 *July* 1973

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART III UNDERGROUND EXCAVATION IN SOFT STRATA

Water Conductor Systems Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE

Ramalayam, Pedder Road, Bombay 26

Members	*Representing*
SHRI K. BASANNA	Public Works Department, Government of Mysore
SHRI N. M. CHAKRAVORTY	Damodar Valley Corporation, Dhanbad
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhra Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (CIVIL AND INVESTIGATION CIRCLE) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
CHIEF ENGINEER (IRRIGATION)	Public Works Department, Government of Tamil Nadu
SHRI J. WALTER (*Alternate*)	
DIRECTOR (HCD)	Central Water & Power Commission, New Delhi
DEPUTY DIRECTOR (PH-I) (*Alternate*)	
DIRECTOR, LRIPRI	Irrigation & Power Department, Government of Punjab
SHRI H. L. SHARMA (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong
SHRI O. P. DATTA	Beas Designs Organization, Nangal Township
SHRI J. S. SINGHOTA (*Alternate*)	
SHRI R. G. GANDHI	Hindustan Construction Co Ltd, Bombay
SHRI M. S. DEWAN (*Alternate*)	
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI M. S. JAIN	Geological Survey of India, Calcutta
SHRI I. P. KAPILA	Central Board of Irrigation & Power, New Delhi
SHRI L. [illegible]. KAPRE	Irrigation & Power Department, Government of Maharashtra

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
Shri Y. G. Patel	Patel Engineering Co Ltd, Bombay
Shri C. K. Chokshi (*Alternate*)	
Shri A. R. Raichur	R. J. Shah and Co Ltd, Bombay
Shri S. Ramchandran	National Projects Construction Corporation Ltd, New Delhi
Shri K. N. Taneja (*Alternate*)	
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh
Shri D. Ajitha Simha, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri G. Raman

Deputy Director (Civ Engg), ISI

Shri O. Vasudevan

Assistant Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
Shri B. S. Kapre	Irrigation & Power Department, Government of Maharashtra
Members	
Shri C. K. Chokshi	Patel Engineering Co Ltd, Bombay
Deputy Director (PH-1)	Central Water & Power Commission, New Delhi
Shri M. S. Dewan	Hindustan Construction Co Ltd, Bombay
Shri K. C. Ghosal	Alokudyog Cement Service, New Delhi
Shri A. K. Biswas (*Alternate*)	
Shri A. R. Raichur	R. J. Shah and Co Ltd, Bombay
Shri G. L. Ramaswamiah	Indian Hume Pipe Co Ltd, Dehradun
Shri S. A. Vijayakeerti (*Alternate*)	
Shri K. Shama Rao	Kerala State Electricity Board, Trivandrum
Shri A. S. Naraynan (*Alternate*)	
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART III UNDERGROUND EXCAVATION IN SOFT STRATA

0. FOREWORD

0.1 This Indian Standard (Part III) was adopted by the Indian Standards Institution on 29 December 1972, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The construction of tunnels involves a large number of problems. Because of the great longitudinal extent of the work many different kinds of conditions are encountered which for maximum economy should be treated differently. This standard covers recommendations for the assistance and guidance of the engineers engaged on projects where tunnelling through soft strata is involved. This standard should, however, be used with caution since, due to the very nature of the work, it is not possible to lay down detailed specifications to cover each and every possible case. The discretion of the engineer-in-charge would be required in many cases.

0.3 This standard is being published in parts. Other parts of this standard are as follows:

Part I Precision survey and setting out

Part II Underground excavation in rock

Section 1 Drilling and blasting

Section 2 Ventilation, lighting, mucking and dewatering

Section 3 Tunnelling method for steeply inclined tunnels, shafts and underground power houses

Part IV Tunnel supports

Part V Concrete lining

Part VI Steel lining

Part VII Grouting

0.3.1 This part covers the special problems involved in the underground excavation in soft strata and should be read along with Part II of this standard as the problems common to both types are not dealt with in this part. The sections of Part II dealing with ventilation, mucking, lighting, dewatering and methods for steeply inclined tunnels and shafts shall apply to this part equally.

0.4 This standard is one of a series of Indian Standards on tunnels. Other standards published so far in the series are:

IS : 4081-1967 Safety code for blasting and related drilling operations

IS : 4137-1967 Safety code for working in compressed air

IS : 4756-1968 Safety code for tunnelling work

IS : 4880 (Part II)-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880 (Part III)-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4880 (Part IV)-1968 Code of practice for design of tunnels conveying water: Part IV Structural design of concrete lining in rock

IS : 4880 (Part VI)-1971 Code of practice for design of tunnels conveying water: Part VI Tunnel supports

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part III) deals with the special problems of underground excavation in soft strata generally. This standard, however, does not cover the innumerable specific problems that arise in the case of excavation in anhydrite rocks, high temperature rocks or in highly swelling and squeezing conditions.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

*Rules for rounding off numerical values (*revised*).

2.1 Adit — A tunnel or open cut driven from the surface to add to the number of working faces of the main tunnel.

2.2 Benching — The operation of removal of the lower portion of the tunnel profile after the top heading has been excavated.

2.3 Cover — Cover on a tunnel in any direction is the distance from the tunnel profile to the outermost rock surface in that direction. However, where the thickness of the overburden is sizeable, its equivalent (reduced to the same density as rock) weight may also be reckoned provided that the rock cover is more than three times the diameter of the tunnel.

2.4 Cut — The group of holes fired first in a round to provide additional free faces for the succeeding shots.

NOTE — This definition applies only to drilling patterns.

2.5 Detonator — A device for producing detonation in a high explosive charge and initiated by a safety fuse or by electricity.

2.6 Drift — A horizontal tunnel usually of a small cross-section and length, driven either from surface for exploration purpose or from an underground face for any purpose.

2.7 Drill Carriage — A vehicle on which one or more drill booms are mounted to permit the drills to be brought easily to their work site and to be removed before blasting.

2.8 Drilling Pattern — It is an arrangement showing location, direction and depth of the holes drilled into the face of a tunnel.

2.9 Easer — Ring of holes drilled around cut holes and fired after cut holes.

2.10 Explosive — Any mixture or chemical compound which is capable of producing an explosion by its own energy. This includes black powder, dynamite, nitroglycerine compounds, fulminate or explosive substance having explosive power equal to or greater than black powder.

2.11 Heading — The face of the tunnel where actual tunnelling operations are in progress. However, when it is prefixed by ‘ top ’ or ‘ bottom ’ it denotes a part section of the tunnel excavated in advance in line of the intended tunnel.

2.12 High Explosive — An explosive which explodes with detonation and detonates at velocities varying from about 1 500 to 7 500 m/s and produces large volume of gases at exceptionally high pressure.

2.13 Jumbo — A mobile platform with number of decks used at the heading of large tunnels for drilling and also for scaling, roof erection of supports, guniting, shotcreting etc.

2.14 Mucking — The operation of removal of the blasted stones/material after the blast has taken place.

2.15 Overbreak — The portion which gets excavated beyond the lines of the intended profile.

2.16 Primer Cartridge — The explosive cartridge into which the detonator has been inserted.

2.17 Scaling — An operation to remove all loose bits of rock from the blasted surface, after the blasting is over.

2.18 Soft Strata — It is a strata of soft rocks, usually sedimentary or metamorphic, which are jointed and faulted, and which require supports to be installed within a very short period of excavation, but which cannot be easily excavated by hand tools.

2.19 Soils — These are defined as disintegrated rocks which require support immediately after and/or during underground excavation and can be excavated by hand tools.

2.20 Stemming — Insert material packed between the explosive charge and the outer end of the shot hole.

2.21 Stoping — Operations for overhead excavation by drilling from an underground face.

2.22 Trimmer — Holes at the periphery of an excavation, fired to give the excavation its final outline.

3. GENERAL

3.1 The practice of tunnelling in soft strata will vary with the softness of the strata, sub-soil water conditions and the facilities available for construction. The choice of tunnelling method to be adopted would depend upon the response of the strata to the technique adopted, which in turn would depend upon the geometry and area of the tunnel sections also. Various tunnelling methods in vogue for soft strata may be classified into the following three main categories: (however, there would be cases falling between any two of the categories and these cannot be defined).

a) *Firm Ground* — Ground where reasonable bridging period is available for installing the conventional supports. This type includes soft and stratified rocks, such as sand stone, shales, cemented sand and gravel and hard clays.

b) *Soft Ground* — Ground where bridging period is so short that conventional supports cannot be installed. In some cases of this type it may be possible to increase the bridging time by methods like shotcreting. This type includes soft or squeezing clay,

damp sand, certain types of gravels or soft earth, some formations of decomposed and/or treacherous rocks.

c) *Running Ground* — This is the ground which requires special treatment before excavation can be done. It may be highly crushed rock, dry sand and gravel, water bearing sand or gravel, silts and muds.

3.2 Location of Portals — Preliminary work required to establish a tunnel face consists of mainly the following items:

a) Open excavation in overburded and rock or excavation of shaft from the bottom of which the tunnel excavation can start.

b) Arrangement for collection of surface water and its drainage by gravity or pumping.

c) Access roads or rail tracks to mucking areas.

d) Erection of winching and hauling equipment.

e) Establishment of a field workshop, compressors, pumps, water lines, ventilation fans ducts, etc.

3.3 The face from where a tunnel satrts has to be decided with reference to the rock cover. The minimum cover with which tunnel can be started depends on the type and structure of rock mass, the size and shape of the tunnel and the pressure of the water in case of hydro-tunnels.

3.3.1 The length up to which it is economical to adopt an open cut in preference to a tunnel depends on the cost of underground and open excavation and the cost of protective works and maintenance involved.

3.3.2 In some cases, the cost of protective works in open cuts becomes very high. However, open excavation has to be continued up to a point where adequate rock cover is available. Under such circumstances cut and cover sections are found more suitable.

3.3.3 Before taking up the excavation of tunnel its face shall be established and alignment of the tunnel marked in accordance with IS : 5878 (Part I)-1971*.

4. TUNNELLING METHODS IN FIRM GROUND

4.1 The methods of excavation of the tunnel depend on the size and shape of the tunnel, the equipment available and the condition of the formation and the extent of the supports necessary and overall economics. With the development of mechanical tunnelling machines, known generally

*Code of practice for construction of tunnels: Part I Precision survey and setting out.

by the name of mole, the two principal methods of excavation are as follows:

a) Traditional methods, that is, by drilling and blasting.

b) Excavation by tunnelling machines.

4.2 Traditional Methods — The common methods are given in **4.2.1** to **4.2.4**. The technique of tunnelling in soft strata will depend on many factors like size and shape of the tunnel, softness, bridging period (stand-up time), and the nature of the strata whether it is intact, stratified, moderately jointed, blocky and seamy, crushed, squeezing and swelling type, dry or water bearing, etc. However, the excavation shall be suitably supported with temporary wooden supports or permanent steel supports, depending upon the type of strata, the size and shape of the tunnel and the tunnelling method adopted. Sometime, the techniques of rock bolting and shotcreting are employed, individually or in conjunction with each other to support the excavated sections, depending upon the type of strata.

4.2.1 *Full Face* — This method may be found suitable for strata where bridging period is long enough to permit ventilation, mucking and supporting and is recommended for tunnels of small size.

4.2.2 *Top Heading and Benching* — This method is recommended in the case of tunnels where full face method is not suitable. The heading may be excavated and supported, if necessary to full length or part length of the tunnel before benching is started.

4.2.2.1 Top heading may be carried ahead of the bench by a convenient length. The heading may have the full width of the tunnel and may be carried down to the springing line.

4.2.2.2 Where bad roof conditions are known to exist in most of the tunnel length or the diameter is large heading may be excavated to full length.

4.2.3 *Bottom Heading and Stoping* — This method is not suitable for soft strata, unless the strata is stabilized by special treatment.

4.2.4 *Drift Method* — In the case of large size tunnels in soft rock, the method of driving small sized tunnels in the face either as a pilot tunnel, or as side and top drifts, is recommended to enable placement of supports prior to the excavation of the bore.

4.2.4.1 *Wall plate drift* — Both heading and benching or top heading methods may sometimes have to be supplemented by drifts at each side on the spring line, advanced beyond the heading face to receive wall plates. These drifts may be driven where the rock is so bad that only a short advance can be made per pull in the heading. The purpose is to permit

use of wall plates of sufficient length to support the top ribs when the subsequent bench blast is taken. The purpose of holding the ribs in the heading until the side ribs in the bench blast are installed will also be served by providing projecting cantilever beams horizontally above the springing line and secured to the ribs in the previous advance.

4.2.4.2 *Side drift* — The side drift method of attack may be employed in a large size tunnel through bed rock which requires support before mucking. The ' rib, wall plate and post ' type of support may be used. A drift may be driven ahead at each side at subgrade in which the posts and wall plates may be erected. If the strata permits, full face operation may then be carried out and the roof ribs may be quickly erected (before mucking) over the exposed wall plates already erected in advance in the side drifts. In case ground conditions do not permit free operations, multiple drift method shall have to be adopted.

4.2.4.3 *Multiple drift method* — This method which is a combination of side drifts and top drift may be frequently employed to get through crushed rock in fault zones which may behave like earth, even if the rock is compacted enough to require light blasting. There are two different methods as below for achieving this:

a) A crown drift is made first and supported by two vertical posts (to be removed later) and a segment of the steel ribs which would form a part of the ultimate steel ribs. Drifts on either side of the central drift are then made and supported by steel rib segments such that these segments along with the segment over the central top drift would form a complete semicircle above the springing. Where the unnel section is large, the above method may be adopted with five segments instead of three as in the above procedure. Benching would then follow the heading done in three or five segments by multiple drifts.

b) A side drift may be driven through the zone at subgrade on each side. A side support in steel or concrete should be constructed in each drift, with adequate provisions for drainage. Should the height of the side walls be too great to build the concrete wall in a single lift, another side drift may be driven immediately above and the concrete side walls carried on up to spring line as shown in Fig. 1. A top centre drift may be then driven through, with the roof support sufficiently above the proposed position of the main tunnel ribs to provide space for crown bars over the ribs. A short section of the drift roof should be blocked on the crown bars and the drift side posts removed. The top drift may be widened out by means of short shots to connect with the roofs of the side drifts. The main arch ribs may be erected on the steel posts or concreted side walls, lagged and packed. The

crown bars supporting the roof members of the top centre drifts should be securely blocked to the ribs, whereupon the next advance should be made. The support for the main tunnel may be the 'continuous rib' type, usually in two piece form although it may be made of more than two pieces. The type of support for the drifts may be the two piece 'continuous rib' or the 'rib and post' type.

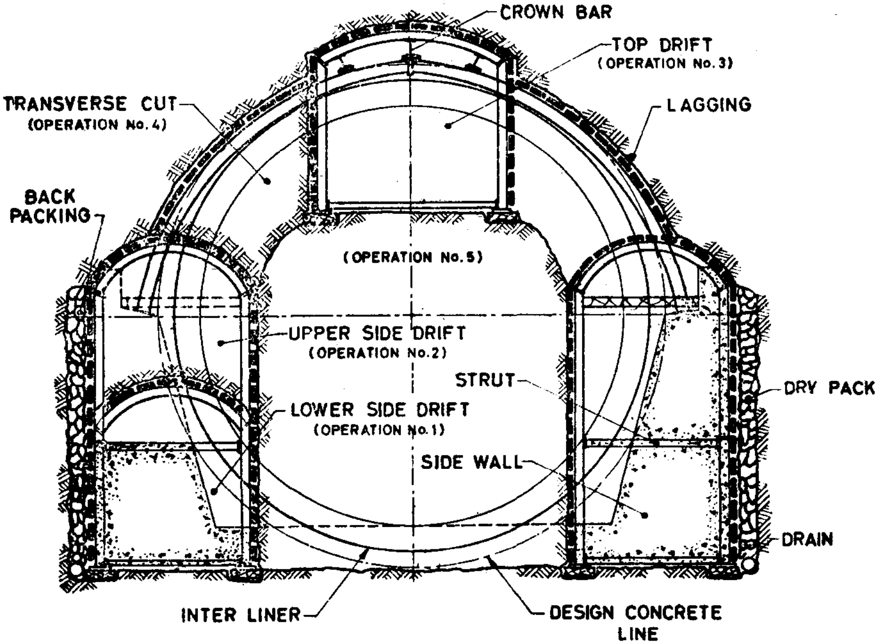


FIG. 1 MULTIPLE DRIFT METHOD

5. TUNNELLING METHODS IN SOFT AND RUNNING GROUND

5.1 Forepoling Method — In the case of soils, either dry or saturated, which require almost instantaneous support, drilling and blasting is never required. Forepoling method is the traditional method and is illustrated in Fig. 2.

5.1.1 In the case of running ground, that is material with no cohesion, such as clean sand or gravel, or highly crushed rock which flows out it may become necessary to hold up the face by breast boards (that is horizontal timber pieces blocking the face, just ahead of the steel supports).

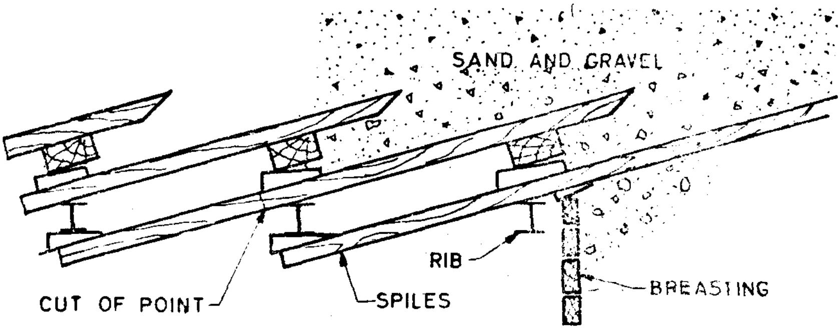


FIG. 2 DIAGRAM OF FOREPOLING METHOD OF SUPPORTING RUNNING GROUND

5.1.2 The boards which are driven ahead to support the ground ahead of the last rib are known as ' spiles ' These may be of timber or of steel. The forepoles act as cantilevers and carry the weight of the ground until their forward ends are supported by the steel rib.

5.1.3 The spiles should be installed as far around the periphery as necessary. The soil should be excavated out after removing the breast boards and the new rib erected in position. Breast boards may then be again refixed on the face. The forepoles should be inserted in such a way that they fan out tangentially from the last rib. In such cases they will not interfere with the tunnel section and it will not be necessary to cut them. They may be embedded in the initial concrete; or the overhanging forepoles may be cut out, if possible, and the process repeated. In such cases the supports should be usually at 600 to 900 mm spacing.

5.2 Tunnelling with Liner Plates — This method may be generally employed for driving steel lined small section drifts or headings on medium soft ground. It may also be adopted for small cross-section drifts even in running ground when combined with compressed air working. The first liner plate should be placed at the crown segment in a pre-excavated cavity at the top and two adjacent liner plates being bolted to it one in each side after the hole has been sufficiently widened. These plates should be temporarily supported by trench jacks or by carefully tightened props. The arch section should be then gradually widened down to the springing line and the liner plate ring so obtained should be wedged outward from wall plates or wall beams placed at the grooves.

5.2.1 The liner plate method may be used in very large tunnels in combination with stiffener rings.

5.3 Needle Beam Method — This method which is a variation of the method described in **5.2** is illustrated in Fig. 3. In this method the full section of the tunnel is broken out. During excavation the plates should be set up one by one, supported by radially set trench jacks or props from a centrally placed longitudinal gird.: called the needle beam which may be fabricated using two heavy steel joists bolted to each other, the space between being filled with hard wood. The length of the needle beam should be chosen to exceed the daily advance by 1·0—1·2 m. It should be placed at the bottom of the top heading, its rear end being supported during the driving by a port from the concrete invert of the tunnel which has already been placed in position. When the needle beam is placed, the trench jacks which formerly stood up on the core should be taken out as the new ones are set from the beam. While in the upper half section timber props may also be used instead of trench jacks, in the lower half steel trench jacks are recommended to counter act the excessive bending deflection of the beam by their restretching especially in bad ground with excessive rock pressure.

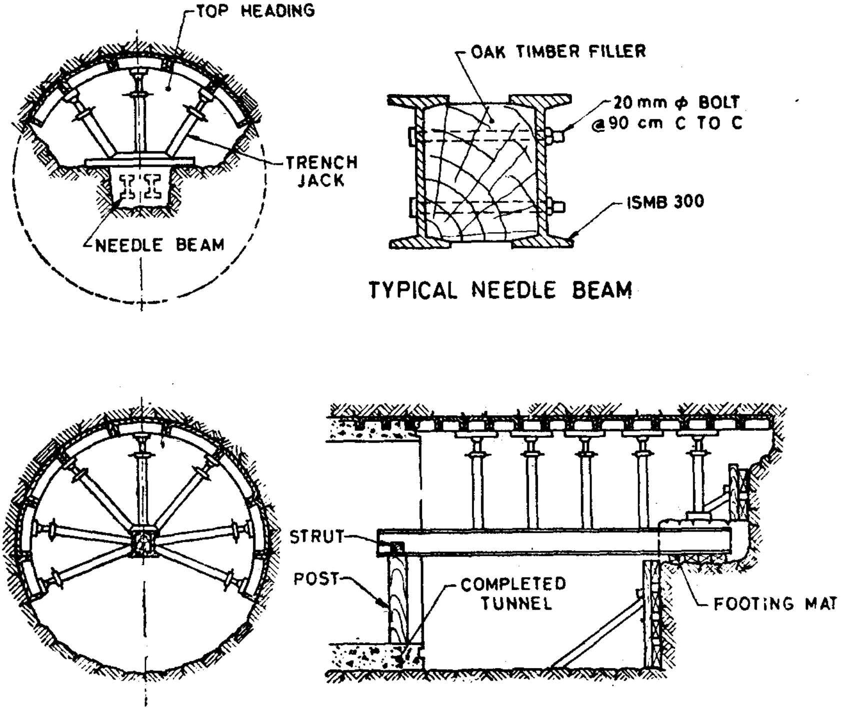


Fig. 3 Needle-Beam Method of Tunnelling with Steel Liner Plates

5.3.1 It is recommended not to excavate sections ahead to distances exceeding one day's concreting in order to avoid development of high rock pressures.

5.3.2 Each row of trench jacks shall be connected by axially placed etchers to prevent its slipping or kicking out on the steel washers.

5.4 Flying Arch Method — In this method (*see* Fig. 4) a top heading is driven, the liner plates of the arch being supported by trench jacks resting on the bench. Each day's drive should be concreted with half round arch forms, handled and filled by hand. A plank footing under the concrete is recommended for a clean even joint. After the heading has been driven about 20 to 25 m the bench should be taken out and the invert concrete placed.

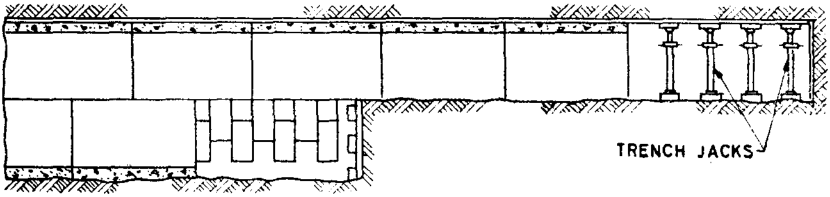


FIG. 4 FLYING ARCH METHOD OF TUNNELING

5.5 Other Methods (Traditional) — In some strata it may be possible to consolidate the ground to be excavated by grouting with cement and/ or chemicals or by freezing the ground. The grouting should be done in an umbrella pattern that is by driving holes inclined away from the periphery to consolidate the strata around the excavation and hold it after excavation till supports are erected. This grouting serves as a forepoling support. This method is of no avail in clays, which do not accept grout.

6. SHIELD METHOD OF TUNNELLING IN CLAYS

6.1 This method of excavation was developed primarily for the excavation of the tube railway tunnels in clay. Basically it is a circular shield of thick steel plates with adequate stiffeners. The excavation of the face is done by hand or pneumatically operated clay spades in sections. The shield is pushed into the excavation by hydraulic jacks, pressing against previously erected linings. The lining conventionally was cast-iron blocks, usually 60 cm long. The segments are held in place by bolts both longitudinally and transversely. As soon as the lining segments are erected and bolted up, the gap between the lining and clay is filled up with pea (passing 13 mm size) gravel blown by pneumatic grouters. This is

followed by packing with cement grout. The lined tunnel thus affords the necessary reaction for the hydraulic jacks to push forward the shield into the clay band. The shield affords complete safety and where the face is stable and does not require breasting, rapid progress has been attained. Recently, the cast-iron segments have been replaced on some projects by segments of precast concrete of high strength usually 421·8 kg/cm^2 using similar bolted connections, gravel packing and grouting.

7. EXCAVATION BY TUNNELLING MACHINES

7.1 A variety of these machines have been developed and built in recent times. These machines are not yet in common use in India because of the high capital costs and non-availability of indegenious cutters.

7.1.1 Basically the tunnelling machines excavate the strata by cutting through it. The cutting is done by rotation of drum or a circular disc, or a circular arm on which are mounted the cutting teeth or wheels or tips. These are of special tungsten carbide or industrial diamonds. The lateral force to press the cutters against the face is provided by hydraulic systems. The machine cuts out the rock, like a drilling machine cutting a small hole in the rock, and the cut rock is conveyed out of the machine by a system of conveyor belts.

7.1.2 The tunnelling machines, especially the cutter heads have to be specially built for specific strata. The designers usually design the cutters on the basis of the crushing strength of the rock through which the tunnel is to be driven.

7.1.3 In self supporting rock or rock requiring very little support, no shield is provided. The machine while excavating, is usually held in position by hydraulic jacks pressing against the sides of the tunnel. Propelling forward is also similarly achieved.

7.1.4 In soft strata requiring supports, the steel supports provide the normal reaction for the hydraulic jacks.

7.1.5 In clays and soils, the machines are fitted with shields extending over the full machines and the cutter heads. The system of supports is usually with precast concrete segments. The machine incorporates a mechanical system for speedy erection of the heavy concrete segments.

7.1.6 All machines are invariably guided by the 'laser' system in alignment.

7.1.7 The speeds achieved are very high compared to traditional methods. Speeds of 1·5 m/h or 30 m per day are not uncommon. These machines to be effective require an equally efficient and fast muck removal system.

7.1.8 The machine facilitates speedly excavation, a clean cut rock face with practically no overbreaks and comparatively less vibration of the strata. No recommendations can be made at the present on the use of these machines in India.

8. OPERATIONS

8.1 Sequence of Operations for Construction of Tunnels — For a tunnel driven in soft strata with traditional methods, the following operations are required:

a) Marking tunnel profile;

b) Setting up and drilling — Necessary for soft rocks only where blasting is necessary. For soils excavation is done without blasting and would require ' forepoling methods ' (*see* **10.1**);

c) Loading explosives and blasting, if required;

d) Removing the foul gases after blasting;

e) Checking misfires;

f) Scaling;

g) Mucking;

h) Erection of supports, or guniting, or shotcreting with/without rock bolts. The process of guniting and shotcreting should generally be concurrent with mucking; the muck pile being used as a platform to gunite/shotcrete the crown and adjoining areas. The lower parts may be gunited/shotcreted after mucking is complete; and

j) In case of use of only steel supports without gunite or shotcrete, the steel supports should be erected after mucking and followed by ' initial concrete ', blocking, lagging and packing. This operation should be done after mucking but simultaneous with the drilling for blasting of the next round.

8.2 Drilling — For blasting a rock in soft strata, it is necessary to drill holes for charging the explosives. The drilling pattern should be worked out by experiments for each particular work and should be modified, if necessary, for every round of blasting to control the overbreaks. The drilling pattern should be such, as to ensure minimum overbreak with minimum or no underbreak and least amount of explosives per unit volume of excavation. Adequate safety precautions shall be taken during drilling operations in accordance with IS : 4081-1967*.

8.3 Equipment — Holes shall be drilled by using pneumatically operated rock drills in conjunction with pneumatic pushers and/or auto-feeds with

*Safety code for blasting and related drilling operations.

ladders or drifters mounted on column bars or drill carriages, as may be found suitable. Only wet drilling shall be permitted. Number of drills is governed by the area of the face of the tunnel. It is generally recommended that one drill is required for each 4 to 5 m^2 face area.

8.4 Diameter of Hole — The diameter of hole at its deepest point shall be at least 6 mm more than the diameter of the cartridge.

8.5 Drilling Pattern — The various patterns used are specified in IS : 5878 (Part II/Sec 1)-1970*. For tunnels in soft strata the following patterns are recommended:

a) Horizontal wedge,
b) Fan cut, and
c) Cylinder cuts.

8.6 Blasting — The recommendations given in IS : 5878 (Part II/Sec 1)-1970* shall be followed. It is, however, recommended that in soft strata instantaneous blasting of a large number of holes should be avoided, and delay detonators should invariably be used to reduce vibrations. Where delay detonators are not available then blasting by the ordinary detonators and fuse coils should be done and delay achieved by adjusting the lengths of the fuse coils.

8.7 Mucking — The recommendations given in IS : 5878 (Part II/Sec 2)-1971† shall be followed.

8.8 Ventilation, Dewatering — Recommendations given in IS : 5878 (Part II/Sec 2)-1971† shall be followed.

8.9 Construction of Supports and Shotcreting — For erection of steel supports and shotcreting the recommendations given in IS : 5878 (Part IV)-1971‡ shall apply. The design of tunnel supports shall be done in accordance with IS : 4880 (Part VI)-1971§.

8.9.1 When multiple drift method is used, the practice given in Appendix A may be adopted for supporting the roof and sides.

9. USE OF TIMBER IN TUNNELS

9.1 Timber has to be used in supporting the rock face from steel ribs, in the form of blocking, bracing and lagging. Timber is also used in forepoling methods.

---

*Code of practice for construction of tunnels: Part II Underground excavation in rock, Section 1 Drilling and blasting.

†Code of practice for construction of tunnels: Part II Underground excavation in rock, Section 2 Ventilation, lighting mucking and dewatering.

‡Code of practice for construction of tunnels: Part IV Concrete lining.

§Code of practice for design of tunnels conveying water: Part VI Tunnel supports.

9.2 It is recommended that use of timber in underground work should be minimized as far as practicable, since timber once fixed can rarely be removed safely and is likely to deteriorate and prove a source of weakness. Total prohibition of timber is, however, not practicable. Properly treated timber may be used.

9.3 Lagging, whenever necessary, may be of the following three types:

a) Timber pieces used as lagging and as shuttering for initial concrete to be removed later,

b) Chain link and shotcreting, and

c) Precast concrete sleepers.

9.4 Collar braces for supports may be timber or steel. Timber should be removed just prior to lining.

9.5 It is very essential to ensure that the roof load is transferred from the excavated tunnel profile to the permanent supports properly. This may be achieved with timber wedges, hand-packed rubble or moist sand shot through concrete pumps or placers. If the gap between the top of the concrete lagging and the tunnel profile is not excessive, the same could be filled with grout. In case of rubble packing, the voids in the rubble should be filled with grout.

9.5.1 Where space does not permit this, timber blocking shall be used and left in position.

9.6 For cribbing in case of large overbreaks, use of concrete sleepers, possibly of light weight aggregates, should be considered in place of timber.

9.7 Shotcreting with or without reinforcement is recommended to be used to reduce the use of supports and timber.

APPENDIX A

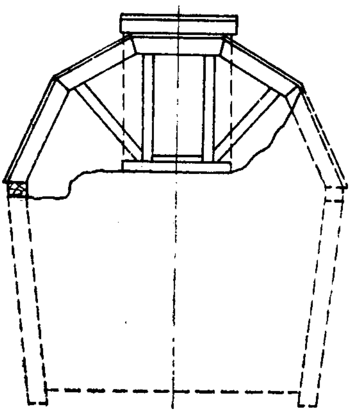
(*Clause* 8.9.1)

METHOD OF SUPPORTING ROOF AND SIDES IN MULTIPLE DRIFT METHOD

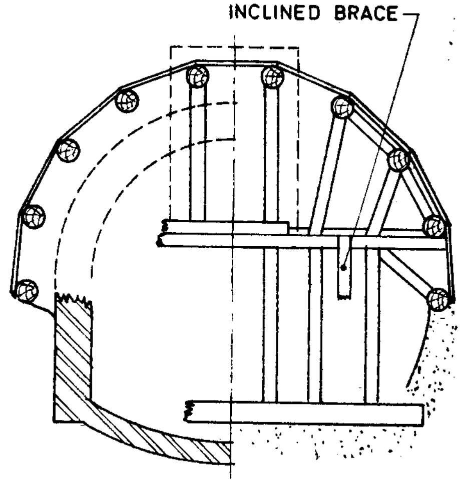
A-1. DETAILS OF METHODS

A-1.1 Some common methods of supporting the roof and sides where tunnelling is done using multiple drift method are given in **A-1.1.1** to **A-1.1.5**.

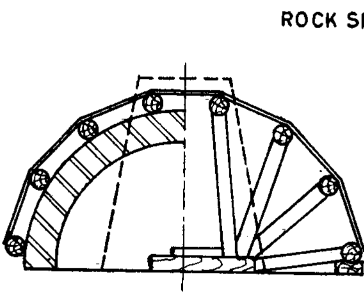
A-1.1.1 *American Method* — In this method (*see* Fig. 5A) a drift is driven at top of arch, in which a cap timber is carefully set supported by two posts resting on a side. The sides of the drift are then broken out



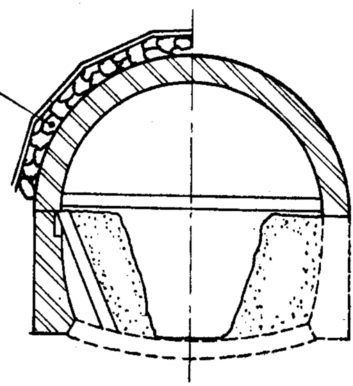
5A AMERICAN METHOD



5 B ENGLISH METHOD



5 C BELGIAN METHOD



5D BELGIAN METHOD

FIG. 5 METHODS OF SUPPORT

and the shoulder timber placed supported by an inclined strut from the sill. The top heading is then widened out until the wall plates can be set in place. The wall plates should be long. Next, the legs are placed and wedged tight to take the load off the centre sill, after which temporary posts are removed. The wall plates are then under-pinned with the plumb posts by cutting out a short wall drift in the bench, deep enough to take either one or two posts.

A-1.1.2 *English Method* — In this method (*see* Fig. 5B) a centre top heading is driven 5 to 8 m ahead of the masonry arch. In this drift, two heavy timbers known as crown bars are erected. The back ends of the timbers are blocked off the arch and the front ends are carried on posts resting on a sill in the floor of the drift. The drift is then widened and another crown bar and lagging placed. This method is continued until the entire arch is carried on longitudinal bars. The forward posts are then underpinned and supported on posts from a sill at floor level.

A-1.1.3 *Belgian Method* — In this method (*see* Fig. 5C and 5D) the top centre heading is driven first and two crown bars set as in the English method, being supported on sills on the bench. The tunnel is widened in the same manner, the additional bars being carried on the same mud sills. A trench is excavated down to grade in the centre of the tunnel and a muck track laid therein. From this trench, side cuts are made to the edge of the arch which at that point is carried on shores from the floor. Pockets are then cut under the arch and the masonry side walls built to underpin the arch. The shores are set and the pockets excavated in alternate spaces until the arch is entirely supported on masonry.

A-1.1.4 *German Method* — This method employs three drifts — one at the crown and two at the bottom along the walls.

A-1.1.5 *Austrian Method* — In this method a centre cut is taken for the full height of the tunnel. This is then widened to full face to allow short sections of masonry to be completed.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones: 331 01 31, 331 13 75 | Telegrams: Manaksanstha (Common to all Offices)

Regional Offices:		*Telephone*
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
*Eastern	: 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola, CALCUTTA 700054	36 24 99
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43 3 16 41
Southern	: C. I. T. Campus, MADRAS 600113	41 24 42 41 25 19 41 29 16
†Western	: Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95

Branch Offices:	
'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48 2 63 49
‡Peenya Industrial Area 1st Stage, Bangalore Tumkur Road BANGALORE 560058	38 49 55 38 49 56
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	6 67 16
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
53/5, Ward No. 29, R.G. Barua Road, 5th Byelane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg (Nampally Station Road), HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71 6 98 32
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76 21 82 92
Patliputra Industrial Estate, PATNA 800013	6 23 05
T.C. No. 14/1421, University P.O., Palayam TRIVANDRUM 695035	6 21 04 6 21 17

Inspection Offices (With Sale Point):	
Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	2 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

---

*Sales Office in Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, Calcutta 700072 — 27 68 00

†Sales Office in Bombay is at Novelty Chambers, Grant Road, Bombay 400007 — 89 65 28

‡Sales Office in Bangalore is at Unity Building, Narasimharaja Square, Bangalore 560002 — 22 36 71

Reprography Unit, BIS, New Delhi, India

AMENDMENT NO. 1 MARCH 1977

TO

IS:5878(Part III)-1972 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART III UNDERGROUND EXCAVATION IN SOFT STRATA

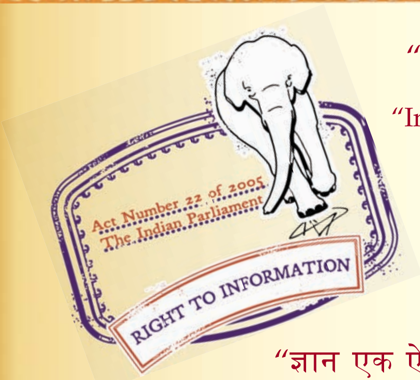
Alteration

(First cover page, pages 1 and 3, title) - Substitute the following for the existing title:

'CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART III UNDERGROUND EXCAVATION IN SOFT STRATA'

IS 5878-4 (1971): Code of practice for construction of tunnels conveying water, Part 4: Tunnel supports [WRD 14: Water Conductor Systems]



BLANK PAGE

IS : 5878 (Part IV) - 1971
(Reaffirmed 2000)

Indian Standard
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER
PART IV TUNNEL SUPPORTS

Fifth Reprint MARCH 1996
(Incorporating Amendment No. 1)

UDC 624.191.1:624.023.9

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 6 *December* 1972

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART IV TUNNEL SUPPORTS

Water Conductor Systems Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE
Ramalayam, Pedder Road, Bombay 26

Members	*Representing*
SHRI K. BASANNA	Public Works Department, Government of Mysore
SHRI N. M. CHAKRAVORTY	Damodar Valley Corporation, Dhanbad
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhra Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (CIVIL AND INVESTIGATION CIRCLE) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
CHIEF ENGINEER (IRRIGATION)	Public Works Department, Government of Tamil Nadu
SHRI J. WALTER (*Alternate*)	
DEPUTY DIRECTOR (DAMS I)	Central Water & Power Commission, New Delhi
DIRECTOR	Land Reclamation, Irrigation & Power Research Institute, Amritsar
SHRI H. L. SHARMA (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong
SHRI O. P. DUTTA	Beas Designs Organization, Nangal Township
SHRI J. S. SINGHOTA (*Alternate*)	
SHRI R. G. GANDHI	The Hindustan Construction Co Ltd, Bombay
SHRI M. S. DEWAN (*Alternate*)	
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI M. S. JAIN	Geological Survey of India, Calcutta
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra
SHRI R. S. KALE (*Alternate*)	
SHRI Y. G. PATEL	Patel Engineering Co Ltd, Bombay
SHRI C. K. CHOKSHI (*Alternate*)	
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI S. RAMCHANDRAN	National Projects Construction Corporation Ltd, New Delhi
SHRI K. N. TANEJA (*Alternate*)	

(*Continued on page* 2)

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

(*Continued from page* 1)

Members	*Representing*
SECRETARY	Central Board of Irrigation & Power, New Delhi
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh
SHRI D. AJITHA SIMHA, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

SHRI BIMLESH KUMAR

Assistant Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra
Members	
SHRI R. S. KALE (*Alternate* to Shri B. S. Kapre)	
SHRI C. K. CHOKSHI	Patel Engineering Co Ltd, Bombay
DEPUTY DIRECTOR (DAMS I)	Central Water & Power Commission, New Delhi
SHRI M. S. DIWAN	The Hindustan Construction Co Ltd, Bombay
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI G. L. RAMASWAMIAH	Indian Hume Pipe Co Ltd, Bombay
SHRI S. A. VIJAYAKEERTI (*Alternate*)	
SHRI K. SHAMA RAO	Kerala State Electricity Board, Trivandrum
SHRI A. S. NARAYANAN (*Alternate*)	
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh

Indian Standard
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART IV TUNNEL SUPPORTS

0. FOREWORD

0.1 This Indian Standard (Part IV) was adopted by the Indian Standards Institution on 27 October 1971, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Very few tunnels are located in perfectly intact strata throughout their whole lengths, the vast magnitude being driven through rock with defects of one kind or another and requiring some support until the permanent lining can be placed. Even intact rock in areas of high initial stresses may require support to prevent popping. Moreover, construction of tunnels involves a large number of problems because of the great longitudinal extent of the work and many kinds of conditions are encountered which for maximum economy should be treated differently. In view of this it has been appreciated that it would be futile to prepare a rigid set of rules or procedures which shall be enforced without leaving any latitude for the exercise of discretion by the site engineer. The aim of this standard is to summarize the well known and proved principles and to describe the commonly used procedures and techniques for providing guidelines which would permit the site engineer to use his discretion.

0.3 In view of the inherent advantages of steel supports over timber supports, the use of the former is recommended and only steel supports are covered in this standard. In olden days timber was used in tunnel supports but now steel has become almost universally adopted as the standard material for supporting tunnels. Sometimes, however, timber may have to be used for tunnel supports.

0.3.1 Steel supports have the following advantages over timber supports:

a) Steel ribs are easier to handle and require much less storage space;

b) Steel ribs when compared to timber would be smaller, section-wise and as such overall cross-sectional area of excavation will be less;

c) Steel ribs become a part of permanent lining and also act as reinforcement. Thus, the thickness of lining will be less;
d) Steel ribs do not deteriorate like timber;
e) Steel ribs can be fabricated to the required shape beforehand in the shop and, therefore, their erection is faster; and
f) No specially skilled personnel are required for erection of steel supports.

0.4 This standard is being published in parts. Other parts of this standard are as follows:

Part I Precision survey and setting out
Part II Underground excavation in rock
Part III Underground excavation in soft strata
Part V Concrete lining
Part VI Steel lining
Part VII Grouting

0.5 This standard is one of a series of Indian Standards on tunnels. Other related standards so far published are given on the fourth cover page.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

0.7 This standard does not cover design of tunnel supports for which a reference should be made to IS : 4880 (Part VI)-1971†.

1. SCOPE

1.1 This standard (Part IV) deals with the types, selection, fabrication and method of fixing of steel supports, rock bolts and shotcreting for tunnels.

2. TERMINOLOGY

2.0 For the purpose of this standard the following definitions shall apply.

2.1 Blocking — It is provided between rock and the ribs to transfer the rock load to the ribs.

*Rules for rounding off numerical values (*revised*).

†Code of practice for design of tunnels conveying water: Part VI Tunnel supports.

2.2 Bracing — It is provided between ribs/posts to prevent their buckling or shifting, unless this purpose is served by lags attached to the frame.

2.3 Bridge Action Period — It is the time which elapses between firing the shots and the breakdown of the equilibrium of the half dome of unsupported section beyond the last rib of the tunnel supports.

2.4 Crown Bars — These are located at the crown of the tunnel parallel to the centre line.

2.5 Lag — The elements which compose lagging (*see* **2.6**).

2.6 Lagging — These are those members of a tunnel support which span the space between the main supporting ribs.

2.7 Minimum Excavation Line (A-Line) — It is the line within which no unexcavated material of any kind and no supports other than permanent structural steel supports shall be permitted to remain.

2.8 Packing — It is the material which is used to fill the empty space between the lagging and rock surface.

2.9 Payline (B-Line) — It is an assumed line (beyond A-Line) denoting mean line to which payment of excavation and concrete lining is made whether the actual excavation falls inside or outside it.

2.10 Rib; Rib and Post or Rib, Post and Invert Strut — These are the components of support system.

2.11 Rock-Load — It indicates the height of the mass of rock which tends to exert pressure on the support.

2.12 Shotcrete — Concrete sprayed under pressure.

2.13 Truss Panels — These serve a function similar to that of crown bars. These are located at the spring line and constitute a temporary support for ribs while taking out the bench and are replaced by posts in the final stage of erection.

2.14 Tunnel Support — It is the structure erected in the tunnel to support the strata surrounding the excavated space until the permanent lining is placed.

2.14.1 *Permanent Supports* — These are tunnel supports which are left in place permanently.

2.14.2 *Temporary Supports* — These are tunnel supports which are erected during excavation and removed before erection of either the permanent lining or permanent supports.

2.15 Wall Plates — These serve as sills for ribs and transmit the load from ribs through blocks or posts to the rock.

3. MATERIAL

3.1 Structural steel sections for tunnel supports shall conform to IS : 808-1964* and IS : 226-1969†.

3.2 Concrete shall generally conform to IS : 456-1964‡.

4. GEOLOGICAL SURVEY

4.1 Necessary geological surveys shall be conducted and a geological section through the centre line of the tunnel shall be prepared showing the approximate position of the boundaries of different types of strata and all the faults or fault zones discovered during the survey. During the survey, defects should receive special consideration. On the basis of the geological survey a geological report shall be prepared containing detailed descriptions of the observed defects in geological terms as well as a tentative classification of the defective rocks in the terms, such as intact, stratified, moderately jointed, blocky and seamy, crushed, squeezing and swelling.

5. TYPES OF STEEL SUPPORT SYSTEMS

5.1 Rock tunnel support systems of steel may be generally classified into the following principal types:

a) Continuous ribs (*see* Fig. 1A);
b) Rib and post (*see* Fig. 1B);
c) Rib and wall plate (*see* Fig. 1C);
d) Rib, wall plate and post (*see* Fig. 1D); and
e) Full circle rib (*see* Fig. 1E)

NOTE — Invert strut may be used in addition, with types (a) to (d) where mild side pressures are encountered (*see* Fig. 1F).

6. SELECTION OF TYPE OF SYSTEM

6.1 General — When choosing the type of support system, the following factors shall be considered:

a) Method of attack;
b) Rock, characteristics, its behaviour and development of rock load; and
c) Size and shape of the tunnel cross section.

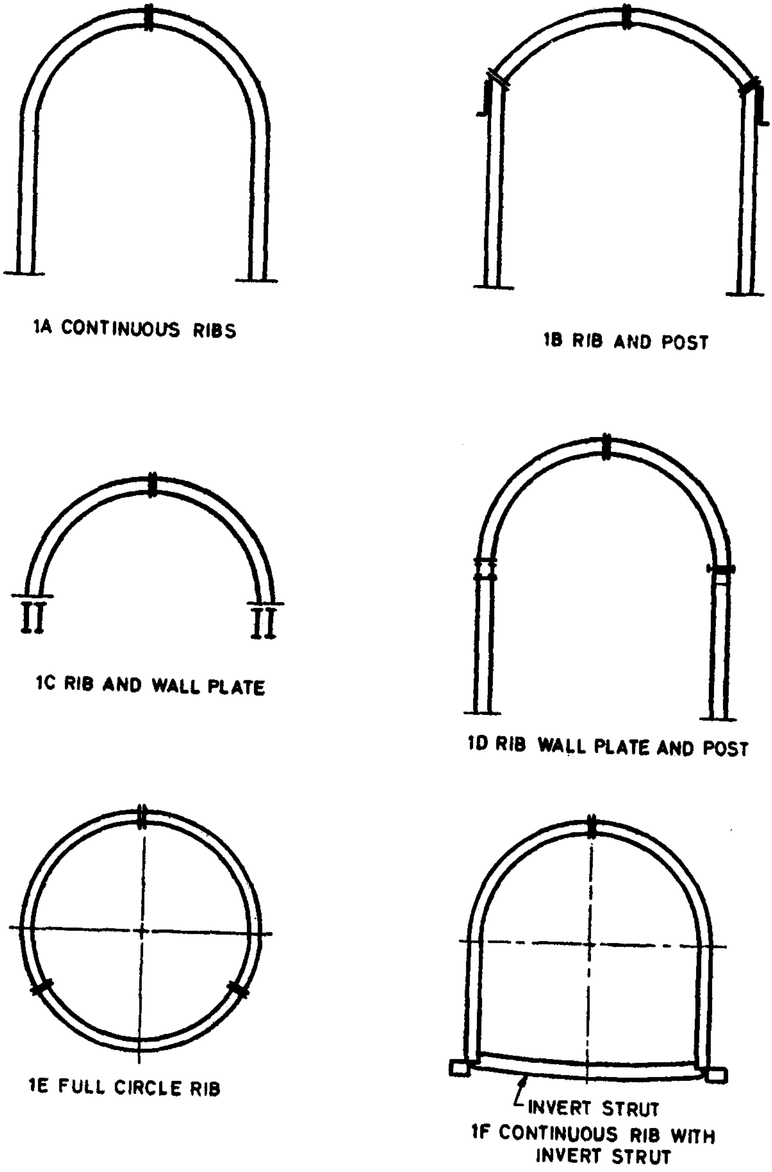
6.2 Selection of Supports with Reference to Surrounding Strata and Shape of Tunnel

---

*Specification for rolled steel beam, channel and angle sections (*revised*).

†Specification for structural steel (standard quality) (*fourth revision*).

‡Code of practice for plain and reinforced concrete (*second revision*).



NOTE — Joints have not been shown in Fig. 1A to 1F and may be located depending upon the construction and fabrication convenience.

FIG. 1 TYPES OF STEEL SUPPORT SYSTEMS

6.2.1 *Continuous Ribs* — This type can be erected more rapidly than the other types and is generally recommended for use in rocks whose bridge action period is long enough to permit removal of gases and mucking. Invert strut may be used in addition where mild side pressures are encountered (*see* Fig. 1F).

6.2.2 *Rib and Post* — This type is generally recommended for use in tunnels whose roof joins the side walls at an angle instead of a smooth curve. It may also be used in large tunnels, such as double-track rail road or two-lane highway tunnels, to keep the size of the rib segments within handling and transporting limitations. Invert strut may be used in addition where mild side pressures are encountered (*see* Fig. 1F).

6.2.3 *Rib and Wall Plate* — This type is generally recommended for use in tunnels with a large cross section with high straight sides through good rock or in large circular tunnels, where it is possible to support the wall plate by pins and where the strata below the wall plate does not require support. This type of support may also be used for tunnelling through spalling rock, provided spalling occurs only in the roof. However, in many cases it is extremely difficult to establish adequate support for the wall plate at any point above the floor-line due to irregularity of the overbreak.

6.2.4 *Rib, Wall Plate and Post* — This type of support permits post spacing to be different from the rib spacing and is generally recommended for use in tunnels with high vertical sides. Invert strut may be used in addition, where mild side pressures are encountered (*see* Fig. 1F).

6.2.5 *Full Circle Rib* — This type is recommended for use in tunnels in squeezing, swelling and crushed rock, or any rock that imposes considerable side pressure.

6.3 Selection of Supports with Reference to Method of Attack for Tunnel

6.3.1 All the types of supports mentioned in **5.1** are suitable for the full face method of attack for rock where required bridge action period for providing supports is available.

6.3.2 Rib and wall plate or rib, wall plate and post are suitable for heading and bench method. The rib, wall plate and post type may be supplemented by truss panels or crown bars, which are accessories developed to handle heavy loads that come quickly by supporting the intervening ribs while the bench is shot out.

6.3.3 Where it becomes necessary to drive first the top heading only due to bad roof conditions the rib and wall plate type of support is generally recommended for use in the heading, and post may or may not be used when the bench is taken out depending on rock conditions.

6.3.4 Where for driving a large size tunnel in poor rock conditions, the side drift method is used, the rib, wall plate and post type of supports are recommended; the wall plate, however, being flat. The posts and wall plates are erected in the drift which is driven ahead at each side at subgrade (*see* Fig. 2)

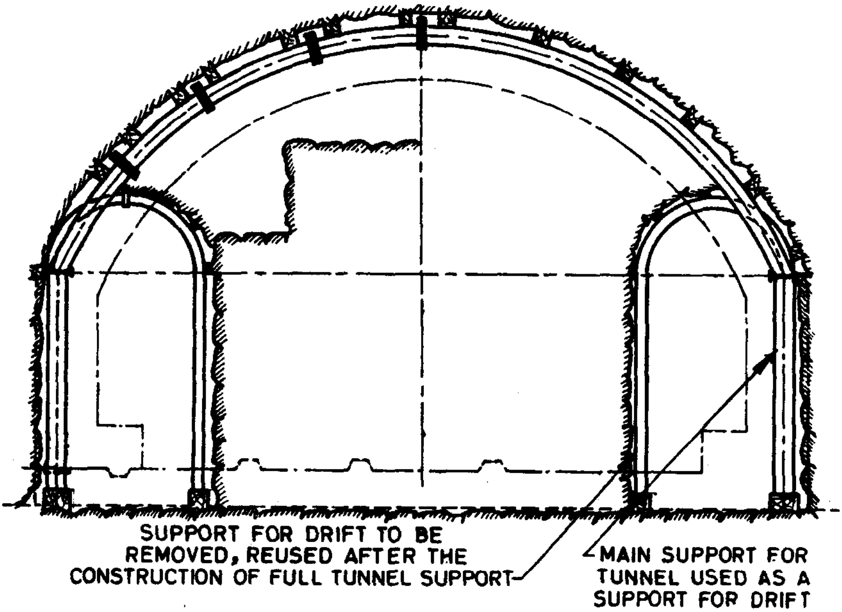


FIG. 2 SIDE DRIFT METHOD

6.3.4.1 Where extreme conditions are encountered, however, break-ups to the crown may be made, leaving a central core. Temporary posts may be quickly placed between the core and the roof at dangerous spots, and crown bars may be slid forward to quickly catch up the roof. The roof ribs should then be placed on the wall plates and securely blocked to take the roof load, after which the temporary posts may be removed.

6.3.4.2 The side drifts themselves usually need support which should be removed just prior to shooting out the core of the main tunnel and re-used ahead. The support system used for the drifts is hybrid. The outer side consists of the posts and wall plate which later becomes a part of the support for the main tunnel, whereas the inner side is a continuous rib (*see* Fig. 2).

6.4 Type of Support for Shafts — For shafts, usually, the full circle rib or segmental ribs are recommended depending upon the slope and rock conditions. In vertical shafts, ribs may be hung from top by hanger rods and blocked and packed. The spacing of hanger rods may be worked out as in the case of tie rods keeping in view that they shall be strong enough to support the weight of ribs.

7. COMPONENTS OF TUNNEL SUPPORTS

7.1 Design of various components of tunnel supports shall be done in accordance with IS : 4880 (Part VI)-1971*.

7.2 Ribs — Ribs may be made of structural beams. H-beams or wide flange beams should be preferred to I-beams, as the wider flanges provide more surface for blocking and lagging, and the section has greater resistance against twisting. Channel sections are not recommended as their unsymmetrical section is prone to twisting, and their flanges are narrow. In small tunnels, however, channels bent about their minor axis may be used under ordinary loads. When choosing the profiles with different weights, it is advisable to select beams of equal depth.

7.3 Posts — The spacing between the posts may be normally equal to that of the ribs. However, by inserting wall plate between the ribs and the posts the spacing of the posts can be made independent of ribs. The posts should be made of H-sections. The depth of these should normally be the same as that of the ribs though in many cases they may be of lighter sections as long as no side pressure is present.

7.4 Invert Struts — Where side pressures are present and tunnel section has not been converted to a full circle, it is necessary to prevent the inward movement of the rib or post feet and in such cases, invert struts should be provided at tunnel subgrade. They should be so attached to the vertical members that they receive the horizontal pressure. They may be curved to form an inverted arch where there is upthrust from the floor.

7.5 Wall Plates — The following three types of wall plates are commonly used:

a) Double beam,

b) Single beam, and

c) Flat wall plate.

7.5.1 The double and single beam wall plates which are intended to resist bending in vertical planes are recommended for use to transmit the

*Code of practice for design of tunnels conveying water: Part VI Tunnel supports,

loads from the ribs on to blocks or posts with a spacing different from that of the ribs. Flat wall plates merely serve as an erection expedient and a convenient surface for horizontal blocking, their resistance to bending in vertical planes being very small; whenever flat wall plates are used, a post shall be placed under each rib.

7.5.2 Double beam wall plates may be made of two I-beams placed side by side, webs vertical, with about a 100 mm space between flanges to give access to the clamping bolt and admit concrete (*see* Fig. 3). The beams should be spaced by vertical diaphragms welded under each rib seat. Ribs and posts should be clamped by toggle plates and bolts, thus avoiding the time required for matching bolt holes. This method of attachment also permits variable spacing of either or both the ribs and the posts. This type of beam provides a broad surface of contact for blocking and to engage ribs and posts. Its box section makes it stable with respect to rolling and twisting.

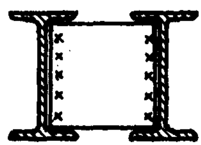


FIG. 3 DOUBLE BEAM WALL PLATE

7.5.3 Single beam wall plates may be H-beams, with web vertical. To enable them to transmit vertical loads from rib to post, they may be reinforced at each rib seat with vertical T-shaped plates, if necessary (*see* Fig. 4). Attachment of ribs and posts shall be made by bolting through the flanges.

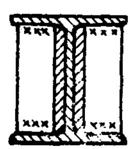


FIG. 4 SINGLE BEAM WALL PLATE

7.5.4 Flat wall plates may be I-beams or wide flange beams used with their webs horizontal. They function merely as a cap for the posts and a sill for erecting roof ribs. The web shall be punched with vent holes to prevent trapping of air when concrete is poured. These holes also serve to pass reinforcing rods if the concrete is reinforced.

7.6 Crown Bars — Crown bars may be built up of double channels as shown in Fig. 5 or may be H-beams or square timber beams. They are located parallel to the axis of the tunnel either resting on the outer flanges of the ribs already erected (*see* Fig. 6A) or attached to the ribs in hangers as shown in Fig. 6B. Crown bars are an accessory, a construction expedient intended to carry loads till the rib sets are erected and the loads permanently transferred to them. They have one of the two functions to perform: to support the roof immediately after ventilation and thereby gain time for the installation of ribs and to support the roof or roof ribs over the bench shot thereby relieving or supplementing the wall plates.

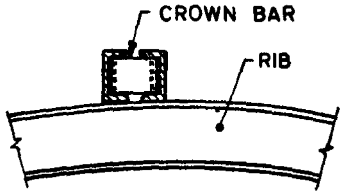


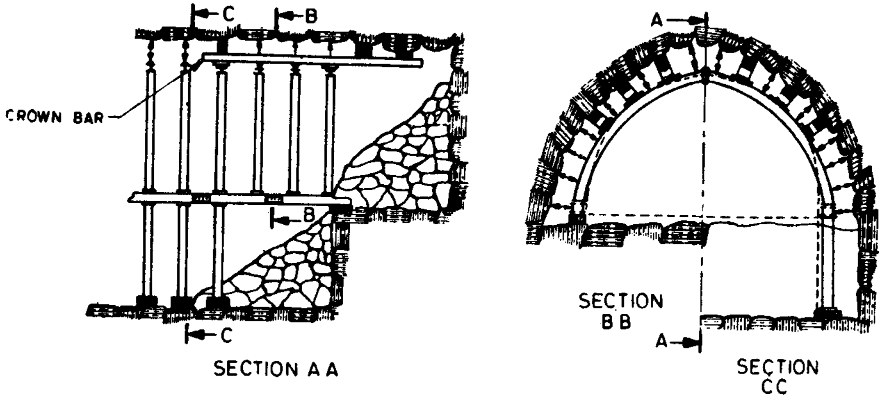
FIG. 5 CROWN BAR

7.7 Truss Panels — These are accessories for use with the combination of rib and post types of support, for the heading and bench or top heading methods of attack and heavy roof loads. Their purpose is to form, in combination with the ribs, a truss to span the gap produced by the bench shot.

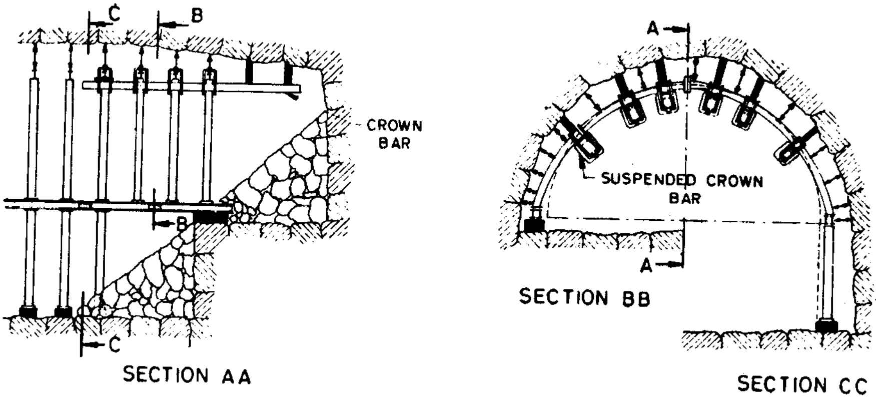
7.7.1 The truss panels should be attached to the inside face of the ribs for a distance of one or more ribs ahead of the bench shot as shown in Fig. 7 and should be left there until posts are installed, at which time they should be removed and sent up ahead. Attachment should be by means of only two bolts at each rib. The truss thus formed may even be designed to carry the roof over two bench shots thus making it more convenient to get in the post.

7.7.2 When truss panels are used, no wall plate is required although the flat wall plate may be used to keep the lower ends of the ribs lined up laterally if it is difficult to block the individual ribs against the rock. The truss panels also eliminate the need for wall plate for drifts.

7.8 Bracing — Longitudinal bracing serves to increase the resistance of ribs and posts to buckling about their minor axis and to prevent a displacement of these set members during blasting. If the space between the ribs or posts is bridged by lagging which is firmly attached to the webs, no such bracing is required. The most common types of bracing which is known as tie rods and collar braces are shown in Fig. 8. The braces may, however, be placed as most convenient.



6A CROWN BARS SUPPORTED OVER RIBS



6B CROWN BARS IN HANGERS

BLOCKING BETWEEN ROCK AND RIB

BLOCKING BETWEEN CROWN BAR AND ROCK RIB

FIG. 6 METHOD OF SUPPORT FOR CROWN BARS

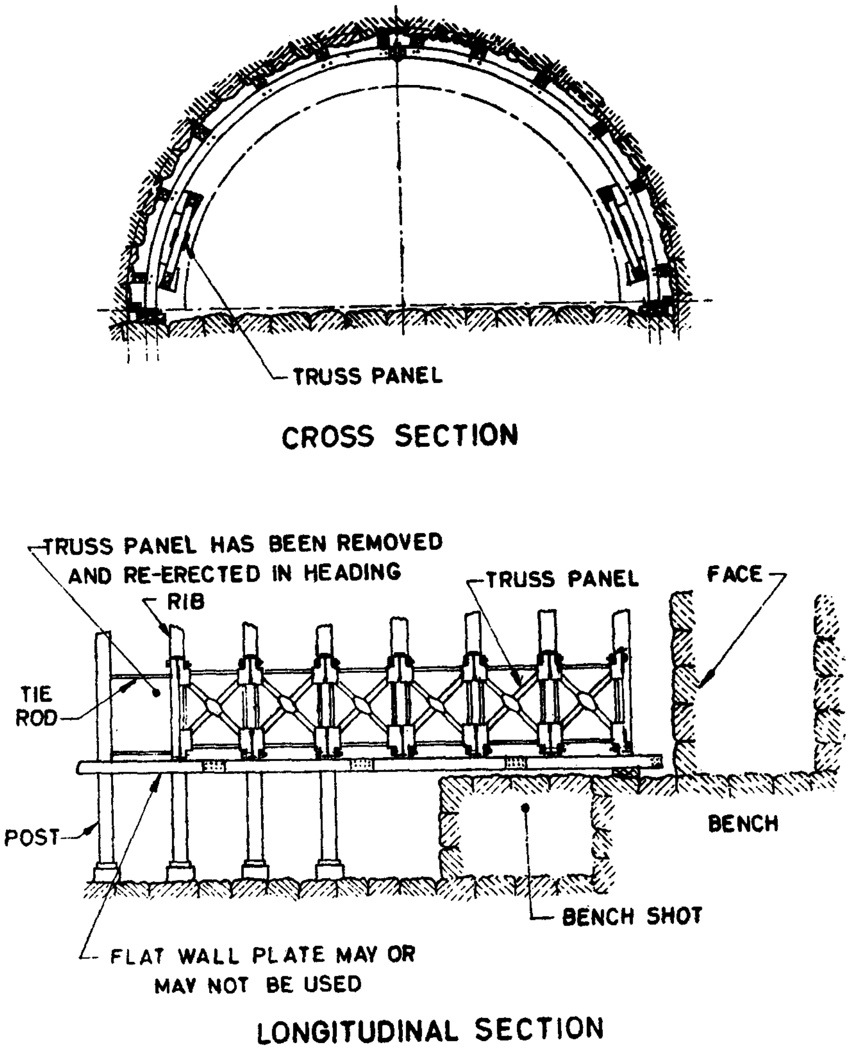


FIG. 7 TRUSS PANEL

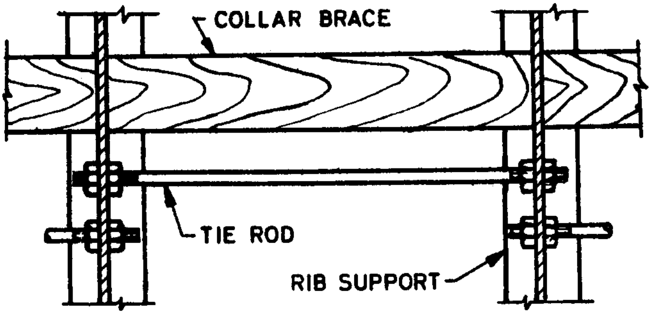


FIG. 8 COLLAR BRACE AND TIE RODS

7.8.1 Tie rods usually may be 15 or 20 mm rods, with thread and two nuts on each end. The length shall be at least 100 mm more than the spacing of the ribs. The spacing of the rods shall be kept such that slenderness ratio l/r for ribs is not greater than 60, where l is the spacing of the rods, and r is the least radius of gyration of the ribs. Collar braces may be usually pieces of timber, 75 × 100 mm, 100 × 150 mm, 150 × 150 mm or of any convenient size. Holes in pairs shall be provided in the web of ribs and posts for the tie rods. Collar braces shall be set in the line between ribs, tie rods inserted and the nuts tightened. Wooden collar braces should be removed before placing final lining.

7.8.2 Spreaders (*see* Fig. 9) which are additional braces may be angles, channels, or I-beams with a clip angle or plate either bolted or welded on each end to the ribs. These are left in the concrete. In tunnels having steep slopes tie rods may be replaced by spreaders.

7.9 Blocking — It is generally done by using timber pieces tightly wedged between the rock and the rib.

7.10 Lagging — It performs one or more of the following functions:

a) To provide protection from falling rock or spalls;
b) To receive and transfer loads to the rib sets;
c) To provide a convenient surface against which to block in case it is not convenient to block directly against the rib, because of irregular overbreak;
d) To provide a surface against which to place back packing;
e) To serve as an outside form for concrete lining, if concrete is not to be poured against the rock; and

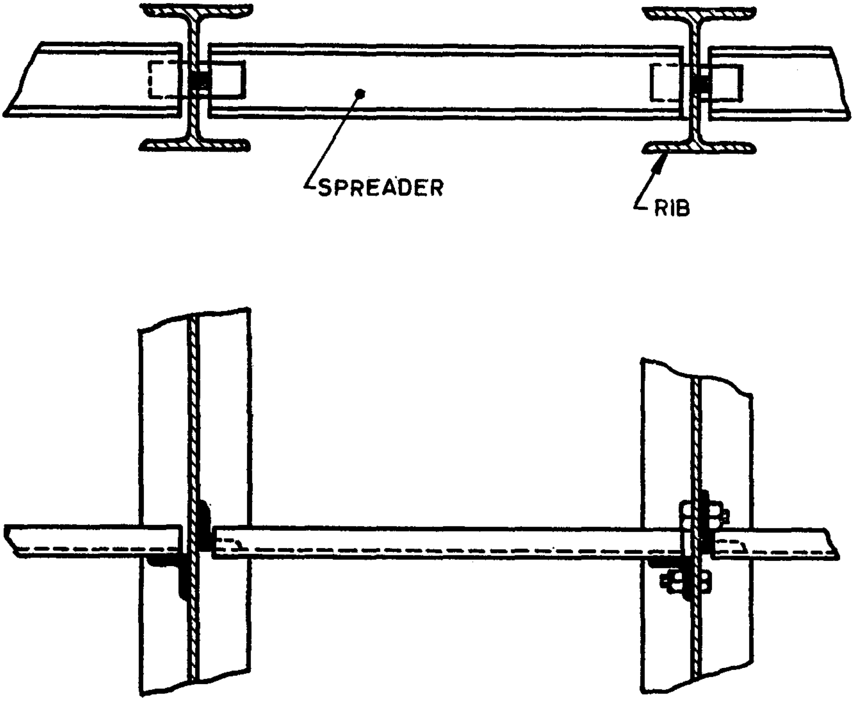


FIG. 9 SPREADER DETAILS

f) To divert water, and to prevent leaching and honey-combing of concrete.

7.10.1 Lagging may be made either of steel, precast concrete or timber. Steel laggings may be made out of channels, beams, beams and plates and liner plates (*see* Fig. 10 and 11). Liner plates, which are pressed steel panels may also be used with or without ribs depending upon the rock conditions. It is recommended that use of timber in underground work should be minimized as far as practicable, since timber once fixed can be rarely removed safely and likely to deteriorate and prove a source of weakness. Total prohibition of timber is, however, not practicable.

7.10.2 The spacing of lags shall be closest at the crown, increasing down to spring line. On the side only an occasional lag should be used, if necessary. Close lagging should be employed where rock conditions make it necessary.

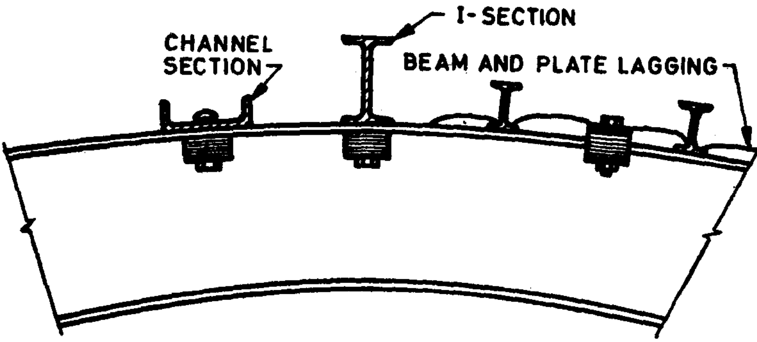


FIG. 10 TYPES OF LAGGING

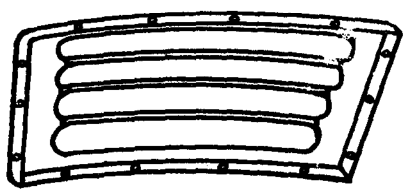


FIG. 11 LINER PLATE

7.11 Packing — The function and type of packing depends on the rock condition. In dry tunnels through jointed rock, packing is only used to fill large cavities produced by excessive overbreak. In broken, crushed or decomposed rock it serves to transfer the rock load to the lags, thereby acting as a substitute for excessive blocking. In squeezing rock it provides continuous contact through the laggings with the rib sets. In jointed water-bearing rock it has primarily the function of a drain.

7.11.1 *Dry Packing* — Dry pack, which usually consists of tunnel spoil (hard) shoveled or hand packed into the space between the lagging and the rock, is recommended for use only where excessive rock loads are not likely to develop. It should be placed simultaneously with the erection of the lagging. Starting at the lowest point, a few lags should be placed and tunnel spoil (hard) shoveled in behind. This procedure should be carried up to the crown at which point it is necessary to pack endwise.

7.11.2 *Concrete Packing* — It is recommended for use where considerable rock loads are anticipated. However, its use is not recommended in case the tunnel supports are designed as yielding supports. Concrete packing may be M-100 concrete conforming to IS : 456-1964*. It may be placed by manual labour or by pneumatic placer to the possible extent. Where excessive loads are anticipated, concrete packing should start from the inner flanges of the steel support so as to embed the whole steel supports in concrete. In such cases it is recommended that precast concrete may be used as additional lagging between two adjacent ribs so as to serve the purpose of form work.

7.11.3 *Pea Gravel Packing* — Pea gravel packing by blowing of gravel is recommended in shield-driven tunnels to fill the annular space around the lining left by the advancing tail of the shield. Gravel should be blown through the grout holes provided in the liner segments as the shield is shoved forward.

NOTE — Pea gravel packing is considered highly desirable kind of packing for most purposes but it has not been practised so far in rock tunnels.

7.11.4 *Grouting* — Grouting to fill any space outside the concrete lining should be usually done after the main concrete lining is in place. But there are occasions where it is desirable to do grouting at low pressure soon after concrete packing. When the main concrete lining is likely to be delayed considerably it is desirable to do grouting at low pressure after concrete packing.

8. ROOF BOLTS

8.1 General — Roof bolting follows the principle of fastening the loose rocks near the surface to the solid rock above, by means of anchor bolts instead of supporting it from below. Roof bolts not only support the surface rock but also assist it to act as a load carrying element.

8.2 Design — The design of roof bolts shall be done in accordance with IS : 4880 (Part VI)-1971†.

8.3 Types of Roof Bolts — The types of roof bolts used commonly have been described in **8.3.1** to **8.3.3**.

8.3.1 *Wedge and Slot Bolts* — These consist of mild-steel rod, threaded at one end, the other being split into halves for about 125 mm length. A wedge made from 20 mm square steel and about 150 mm long shall be inserted into the slot and then the bolt driven into the hole which will make the split end to expand and fit tight into the hole forming the anchorage. Thereafter, a 10-mm plate washer of size 200 × 200 mm

*Code of practice for plain and reinforced concrete (*second revision*).

†Code of practice for design of tunnels conveying water: Part VI Tunnel supports.

shall be placed and the nut tightened (*see* Fig. 12). The efficiency of the splitting of the bolt by the wedge depends on the strata at the end of the hole being strong enough to prevent penetration by the wedge end and on the accuracy of the hole drilled for the bolt. The diameter of such bolt may be 25 mm or 30 mm.

8.3.2 *Wedge and Sleeve Bolt* — This generally consists of a 20 mm diameter rod at one end of which is a cold-rolled threaded portion. The other end of the rod is shaped to form a solid wedge forged integrally with the bolt and over this wedge a loose split sleeve of 38 mm external diameter is fitted (*see* Fig. 13). The anchorage is provided in this case by placing the bolt in the hole and pulling it downwards while holding the sleeve by a thrust tube. Split by the wedge head of the bolt, the sleeve expands until it grips the sides of the tube. Special hydraulic equipment is needed to pull the bolts.

8.3.3 *Perfo Bolts* — This method of bolting consists of inserting into a hole a perforated cylindrical metal tube which has been previously filled with cement mortar and then driving into the tube a plain or ridged bolt. This forces part of the mortar through the perforations in the tube and into intimate contact with the sides of the bore hole thus cementing the bolt, the tube and the rock into one homogeneous whole (*see* Fig. 14). The relation between the diameter of the bore hole and the diameter of perfo sleeve and bolts is given in Table 1.

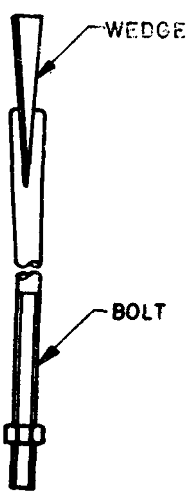


FIG. 12 WEDGE AND SLOT BOLT

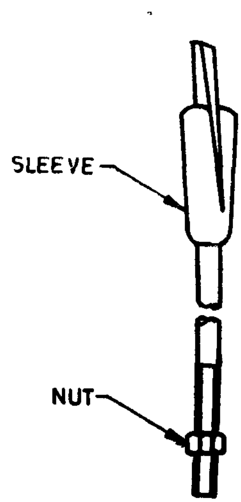


FIG. 13 WEDGE AND SLEEVE BOLT

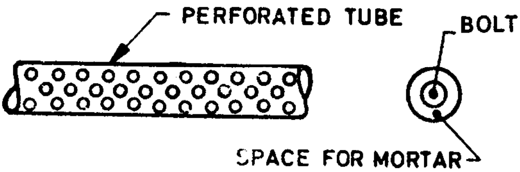


FIG. 14 PERFO BOLT

TABLE 1 DIAMETER OF PERFO SLEEVE AND BOLTS

All dimensions in millimetres.

DIA OF BORE HOLE	DIA OF PERFO SLEEVE	DIA OF BOLTS
(1)	(2)	(3)
40	36	30
38	31	25
31	27	18

9. GUNITING

9.1 It is recommended that guniting with a mix of 1 : 3 to 1 : 4 may be used as a form of temporary support with or without wire mesh to prevent deterioration of rock surface. When used in combination with rock bolts and chain link fabric, it forms a permanent support.

10. SHOTCRETE

10.1 General — Shotcrete for tunnel supports may be used by itself as a thin skin type reinforcement or used in combination with rock bolts, wire mesh and other more conventional tunnel reinforcements. Details are given below:

a) Shotcrete is forced into open joints, fissures, seams and irregularities in the rock surface and in this way serves the same binding function as mortar in a stone wall.

b) Shotcrete hinders water seepage from joints and seams in the rock and thereby prevents piping of joint filling materials and air and water deterioration of the rock.

c) Shotcrete's adhesion to the rock surface and its own shear strength provide a considerable resistance to the fall of loose rock blocks from the roof of a tunnel.

d) A thicker shotcrete layer 150 to 250 mm provides structural support, either as a closed ring or as an arch type member.

10.2 Mix — Shotcrete shall be mixture of cement, sand and aggregate. The proportion of cement to aggregate in shotcrete may be normally 1 : 3 or 1 : 4; the aggregate being a mixture of sand and about 20 percent aggregate varying from 5 to 20 mm. The dry mixture of shotcrete shall be applied under pressure of about 3·5 kg/cm² by means of a nozzle through a concrete gun. To this nozzle, water shall be added also under pressure through a separate pipe. A quick setting agent shall be added to the dry mixture.

10.3 Thickness — The thickness of shotcrete required depends upon the type of rock, the extent of stratification and/or joints, blockiness and also the size of the tunnel. The thickness may normally range from 50 to 150 mm and whether it should be used plain or with wire-mesh anchored to rock will depend upon the actual site conditions in each case.

NOTE — As in the case of rock bolts, the application of shotcrete has not yet reached the stage when it is possible to laydown a design criteria. Considerable experience has been accumulated in regard to the use of shotcrete as underground support without any consideration for the type of pressure or rock-shotcrete interaction that was dealt with during construction. The results of such massed experience are frequently expressed in the form of rule-of-thumb guides for the selection of a shotcrete design.

11. FABRICATION

11.1 The ribs shall generally be bent cold. For small jobs ribs may be fabricated as polygons.

11.2 The accuracy of bending shall be such that after bending each segment shall conform to true template at ends. Intermediate portions may depart from true template by not more than ± 10 mm. The web shall be true and wrinkles or buckles shall not exceed 5 mm when measured from a straight edge held flush against either side of web on radial plane.

11.3 To ensure proper space as the crown after wedging, the ribs shall be fabricated to a slightly larger radius than theoretically computed.

11.4 In tunnels with small cross section the crown joints may be 'kicked up' or the ribs set high to accommodate the concrete delivery pipe as shown in Fig. 15.

11.5 All welding for fabrication of supports shall conform to the provisions of IS : 816-1969*.

11.6 Erection Tolerances — The steel supports shall be erected at spacings shown in the drawings and kept blocked and wedged tightly until final concreting. They shall be erected either vertical or in a plane

*Code of practice for use of metal arc welding for general construction in mild steel (*first revision*).

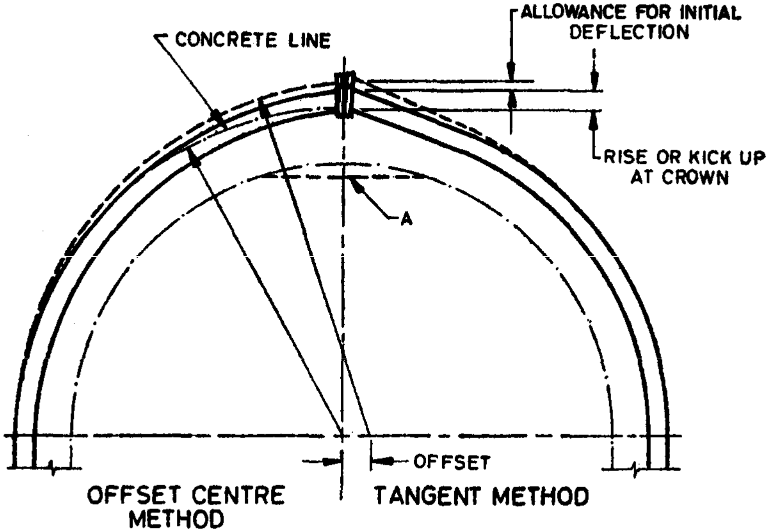


FIG. 15 KICK UP AT CROWN IN RIBS

at right angles to the slope of the tunnel as may be found practicable. The erection shall be done within the following tolerances:

a) *Spacing of Ribs* — Average of three measurements taken around periphery shall not differ from the spacing shown on the drawings by more than ± 3 cm.

b) *Internal Dimension* — Dimensions between the inner flanges of ribs shall be checked at 2 or 3 points in the horizontal plane and such dimensions shall not vary from the theoretical dimensions by more than ± 3 cm.

c) *Level at Crown* — Level of the crown shall be within − 2 cm and + 4 cm of the required level.

d) *Deviation in Vertical Plane* — The deviation from vertical or the required inclination shall not be more than ± 20 mm when measured at the lowest point.

e) *Spacing Between the Tie Rods* — This shall be as shown on the drawings with a tolerance of ± 3 cm.

f) *Gap Between the Joints* — The gap between joints of the butt plates of the ribs shall not be more than 5 mm.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones: 331 01 31, 331 13 75 — Telegrams: Manaksanstha (Common to all Offices)

Regional Offices:	*Telephone*
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
*Eastern : 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola, CALCUTTA 700054	36 24 99
Northern : SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43 3 16 41
Southern : C. I. T. Campus, MADRAS 600113	41 24 42 41 25 19 41 29 16
†Western : Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95

Branch Offices:	
'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48 2 63 49
‡Peenya Industrial Area 1st Stage, Bangalore Tumkur Road BANGALORE 560058	38 49 55 38 49 56
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	6 67 16
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
53/5, Ward No. 29, R.G. Barua Road, 5th Byelane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg (Nampally Station Road), HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71 6 98 32
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76 21 82 92
Patliputra Industrial Estate, PATNA 800013	6 23 05
T.C. No. 14/1421, University P.O., Palayam TRIVANDRUM 695035	6 21 04 6 21 17

Inspection Offices (With Sale Point):	
Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	2 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office in Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, Calcutta 700072 — 27 68 00

†Sales Office in Bombay is at Novelty Chambers, Grant Road, Bombay 400007 — 89 65 28

‡Sales Office in Bangalore is at Unity Building, Narasimharaja Square, Bangalore 560002 — 22 36 71

Reprography Unit, BIS, New Delhi, India

AMENDMENT NO. 2 OCTOBER 1992
TO
IS 5878 (Part 4) : 1971 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART 4 TUNNEL SUPPORTS

(*Page* 19, *clause* **8.3.3**) — Insert the following new clauses after **8.3.3**:

'**8.3.4** *Mechanically Anchored, Tensioned and Grouted Bolts*

This generally consists of a wedge, attached to the bolt shank which is pulled into a conical anchor shell forcing it to expand against the drill hole walls. A rubber grout seal is used to centre the bolt in the hole and to seal the collar of the hole against grout leakage. Grout is then injected into the collar end of the hole and the return pipe is extended for the length of the hole. The grout injection is stopped when the air has been displaced and when grout starts flowing from the return tube (*see* Fig. 16). These type of bolts can be tensioned immediately after installation and grouted at a later stage when short term movements have ceased.

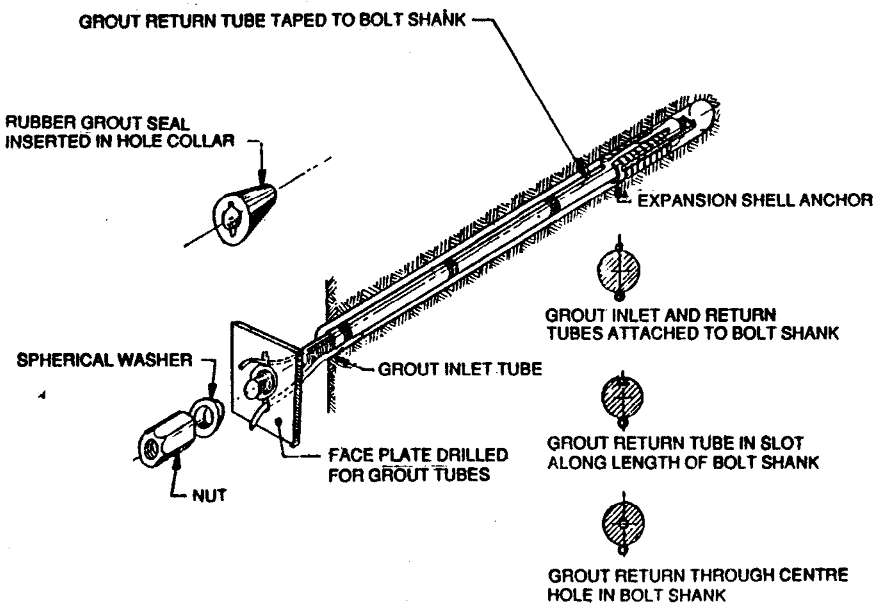


FIG. 16 TYPICAL DETAILS OF MECHANICALLY ANCHORED, TENSIONED AND GROUTED BOLTS

8.3.5 *Resin Grouted, Tensioned Threaded Bar Bolts*

This method of bolting consists of resin and catalyst contained in plastic capsules, the catalyst being separated in a glass or plastic container in the resin. These capsules are pushed into the hole with a loading stick and the bar is then inserted. Rotation of bar during insertion breaks the plastic containers and mixes the resin and catalyst (*see* Fig. 17). They are very convenient and simple to use. Very high strength anchors can be formed in rock of poor quality. These can be increasingly used in critical applications in which cost is less important than speed and reliability.'

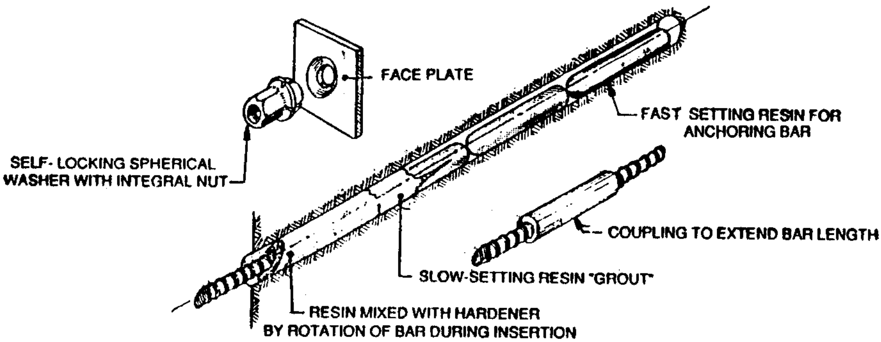


FIG. 17 TYPICAL DETAILS OF RESIN GROUTED, TENSIONED THREADED BAR BOLTS

(RVD 14)

IS 5878-5 (1976): Code of practice for construction of tunnels conveying water, Part 5: Concrete lining [WRD 14: Water Conductor Systems]

BLANK PAGE

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART V CONCRETE LINING

(First Revision)

Third Reprint SEPTEMBER 1994

UDC 624.191.2:69.034.92

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3 November 1976

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART V CONCRETE LINING

(*First Revision*)

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
Dr S. P. Garg	Irrigation Department, Government of Uttar Pradesh, Lucknow
Shri M. S. Jain	Geological Survey of India, Calcutta
Shri N. K. Mandwal (*Alternate*)	
Joint Director Standards (SM)	Ministry of Railways, New Delhi
Deputy Director Standards (B&S)-1 (*Alternate*)	
Shri B. S. Kapre	Irrigation Department, Government of Maharashtra, Bombay
Shri S. M. Bhalerao (*Alternate*)	
Shri D. N. Kochhar	National Projects Construction Corporation Ltd, New Delhi
Shri G. Parthasarthy (*Alternate*)	
Shri Y. G. Patel	Patel Engineering Co Ltd, Bombay
Shri C. K. Chokshi (*Alternate*)	
Shri S. N. Phukan	Assam State Electricity Board, Shillong
Shri S. C. Sen (*Alternate*)	
Shri A. R. Raichur	R. J. Shah & Co Ltd, Bombay
Shri S. R. S. Sastry	Mysore Power Corporation Ltd, Government of Karnataka, Bangalore
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh, Lucknow
Shri B. T. Unwalla	Concrete Association of India, Bombay
Shri E. T. Antia (*Alternate*)	
Shri D. Ajitha Simha, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri K. K. Sharma
Assistant Director (Civ Engg), ISI

Panel For Construction of Tunnels, BDC 58 : P2

Convener	
Shri B. S. Kapre	Irrigation Department, Government of Maharashtra, Bombay
Members	
Shri C. K. Chokshi	Patel Engineering Co Ltd, Bombay
Deputy Director (HCD-I)	Central Water Commission, New Delhi
Deputy Director Research (SM)-1	Ministry of Railways, New Delhi
Deputy Director Standards (B&S)-1 (*Alternate*)	
Shri R. K. Joshi	Hindustan Construction Co Ltd, Bombay
Shri R. M. Vidwans (*Alternate*)	
Shri K. Ramabhadran Nair	Kerala State Electricity Board, Trivandrum
Shri John M. John (*Alternate*)	
Shri A. R. Raichur	R. J. Shah & Co Ltd, Bombay
Shri G. L. Ramaswamiah	Indian Hume Pipe Co Ltd, Bombay
Shri S. A. Vijayakeerty (*Alternate*)	
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh, Lucknow

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART V CONCRETE LINING

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part V) was adopted by the Indian Standards Institution on 31 August 1976, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 This Indian Standard was first published in 1971 and is being revised with a view to keeping abreast with the technological developments that have taken place in the field of tunnel design and construction.

0.3 The construction of tunnels involves a large number of problems. Because of the great extent of variations in the nature of the work many different kinds of conditions are encountered which for maximum economy, consistent with technical requirements should be treated differently. This standard covers recommendations which would be generally applicable to construction of tunnels for the assistance of engineers engaged on such projects. This standard should, however, be used with caution since due to the very nature of the subject it is not possible to lay down detailed specifications to cover each and every possible case and the discretion of the engineer-in-charge would be required in some cases.

0.4 Lining in tunnels is technically an important component and generally constitutes 30 to 40 percent of the total cost of the tunnel. Therefore lining operation requires considerable study and careful planning. Tunnels forming part of water conductor system have to be invariably lined with cement concrete from structural and hydraulic considerations with some exceptions when the rock is extremely hard, sound and massive like granite and/or where the tunnel may be in operation for short periods in a year,

0.5 This standard has been published in parts. Other parts of this standard are as follows:

Part I Precision survey and setting out

Part II Underground excavation in rock

Section 1 Drilling and blasting

Section 2 Ventilation, lighting, mucking and dewatering

Section 3 Tunnelling method for steeply inclined tunnels, shafts and underground power houses

Part III Underground excavation in soft strata

Part IV Tunnel supports

Part VI Steel linings

Part VII Grouting

1. SCOPE

1.1 This standard (Part V) lays down specifications and procedures for placing concrete lining for tunnels conveying water.

2. REQUIREMENTS

2.1 The requirements for concrete lining of tunnels shall be carefully drafted as the conditions for lining tunnels are quite different from those of other cement concrete works. Requirements of lining of tunnels are special on account of curvature, thin sections and difficulties in placement and compaction in restricted spaces.

2.1.1 All the requirements for coarse and fine aggregates, cement, water, and concrete grading and corresponding strength in accordance with IS : 456-1964* shall apply. On account of curvature, irregularities in rock profile, thin sections and placing of concrete generally required to be done either through a concrete pump or pneumatic placer, the concrete necessarily requires to be flowy to avoid seggregation and to ensure proper filling in. The slump of concrete should not be less than 10 cm and the sand content shall be more than that specified in IS : 456-1964*. The cement content shall also be more than what is indicated by laboratory tests alone (*see* Note below). Where concrete is placed directly, as in inverts and kerbs, the slump should be reduced to 5 cm. Use of natural aggregates, especially sand, either wholly or partly, improves the pumpability of concrete and is recommended commensurate with practicability and economy. The maximum size of aggregate shall not exceed 40 mm. This should, however, be reduced suitably for specific locations and conditions.

NOTE — The cement content in concrete may vary from 350 to 400 kg/m³. However, in particular locations where experience indicates, the minimum cement content may be reduced to 325 kg/m³ where natural aggregates are used and there

*Code of practice for plain and reinforced concrete (*second revision*).

is no hindrance of supports or reinforcement. Where crushed aggregates are used and where supports or reinforcement come in the way, the minimum cement content may be suitably increased to ensure adequate workability. All the above mentioned cement contents are applicable to concrete placed through a concrete pump or by pneumatic placer.

2.1.2 It is advisable to use air entraining agent, to entrain up to 4 percent of air for improving workability of concrete.

3. CONTROL OF SEEPAGE WATER

3.1 Seepage water shall be suitably controlled and prevented from getting mixed with green concrete in the lining.

4. APPROPRIATE TIME FOR PLACING CONCRETE LINING

4.1 The appropriate time for placing concrete lining will be governed by the conditions of rock tunnelled through. In cases where due to tectonic forces rock dilates, it is advisable to allow sufficient time for such dilations to reduce to reasonable limits to ensure that concrete lining will not fail by cracking due to heavy and unequal external forces. In cases where rock may not dilate much but may deteriorate in structure causing spalling, placing of a thin layer of concrete between steel ribs to support full surface of the rock and transfer the forces to the steel supports would be desirable (in certain conditions, shot-crete may be resorted to in place of such blocking concrete, taking care to ensure that the gap between external flange of the support and rock is fully filled up). Blocking concrete or shot-crete has to be placed with minimum possible time lag after excavation. Shot-crete can be applied more quickly than blocking concrete. In cases where rock is of better type than referred to above, concrete lining may come at any time convenient to suit the construction programme and practical considerations.

5. SEQUENCES OF LINING

5.1 The sequence of concrete placement for tunnel lining depends on the shape of the tunnel, its size, the nature of the rock strata and the type of form work and other plant and equipment used and has to be selected taking into account the construction schedule and progress scheduled to be achieved for the particular work. The sequences generally adopted for lining in tunnels are:

a) placing concrete to form the kerbs first, followed by side walls and arch and finally the invert;

b) placing concrete to form the invert first followed by sides and arch; and

c) placing concrete for the invert, side walls and arch all at one time.

5.1.1 The sequence given at **5.1** (a) is suited for horse-shoe, D-shaped and other flat bottomed and wide tunnels. The kerb shall be built up to a section of sufficient width to serve as a base for the errection of forms for sides and shall be properly anchored and made stable to withstand the loads of concrete lining and form work. After the kerb is constructed, the lining of the sides and arch follows. The sides of the kerb against which the sides and the invert concrete will be laid later should preferably be radial to their respective curvatures. This sequence has the advantage that all operations of concreting kerb, placing of shutters and forms and lining of sides and arches can be done with minimum disturbance to the track lines on the floor and for movement of other traffic. Then the track lines and other service lines are removed and invert concreting is done last. By this method the bottom concrete surface does not get damaged. An additional advantage in this is that it permits of concreting the sides and arch simultaneously with excavation with a suitable gap.

5.1.2 The sequence described at **5.1** (b) is suitable when the bottom of the tunnel is narrow or when the section is circular. The invert concreting is done first and a regular base for the erection of the form work for sides and arches is obtained making further work easier. But this procedure entails the removal of trolley tracks and other service lines laid on the floor and again laying them over the concreted invert for lining of sides and arch. It has also the disadvantage that the concrete surface of the invert is likely to get damaged during the operations for laying the overt. These practical difficulties increase if transport is by trucks.

5.1.2.1 In tunnels through weak strata, where the tunnel floor tends to wear out fast or heave up, the above sequence is required to be adopted. In cases where large horizontal thrusts are encountered, the placing of invert concrete in advance of lining of sides, serves as strutting between the sides. The concrete surface can be protected suitably.

5.1.3 The sequence described at **5.1** (c) is possible only in small and circular tunnels. It is difficult to be adopted in ordinary course and may be resorted to only where concrete pumping facilities are available and construction programme demands it. It has some advantages in steeply inclined tunnels. These present problems in proper alignment along the tunnel axes.

5.1.4 In case of tunnels through soft rock, when it is found that the rock strata is likely to collapse, it may become necessary to provide a primary lining over and between the steel supports (if provided) at the time of driving the tunnel, or by shot-creting immediately. (*see* **4**).

NOTE — Different types and methods of primary and main lining are described in IS : 5878 (Part III)-1972*.

*Code of practice for construction of tunnels conveying water; Part III Underground excavation in soft strata.

6. FORM WORK

6.1 General — Generally for tunnel lining steel forms are used in the interest of speed and economy due to their multiple use. There are various types of form work used for tunnel lining, such as rib and plates, rib and laggings, travelling shutters with or without telescoping. Timber formwork has to be resorted to in sharp bends, transitions and junctions. The use of a particular type for a job depends on the size, shape and the length of tunnel.

6.1.1 In a rock tunnel where the concrete is placed mechanically, forms may be removed after 16 to 24 hours from the placing of last batch of concrete. The form surface shall be oiled before concreting to avoid concrete sticking to it.

6.2 Rib and Plate or Rib and Lagging — This type of form work may be used for tunnels of medium size, that is, up to 5 m diameter. When concrete is to be hand placed on short tunnels, this type of form work is convenient.

6.2.1 Ribs made of either channels or T-sections placed at intervals of about 1 m according to the thickness of the concrete lining shall be erected firmly over the invert and either adequately stiffened steel plates or timber lagging shall be fixed from the bottom upwards as the concrete rises.

6.3 Travelling Non-telescoping Form Work — In this case the whole form work is preassembled and mounted on a travelling frame fixed with wheels running on a track and screw jacks are provided for collapsing the form work, when required. In all types or travelling forms the sections are hinged to permit collapsing. Jacks are required for bracing and aligning the forms.

6.3.1 This type is easy and economical to move. For this type of forms concrete for the sides and arch may be placed in one continuous operation. The traveller which carries the form structurally forms a part of the form work. The forms are made in units 6 to 12 m long and can be struck and reassembled quickly depending on the requirements of construction traffic and matching concreting equipment.

6.4 Travelling Telescoping Form Work — This is so designed that the back unit can be collapsed and moved forward through the front unit without disturbing it. The side plates are hinged to the arch plate so that it is possible to collapse them. The traveller is equipped with jacks and other accessories for this purpose. The form work shall be self-supporting while travelling in the collapsed condition also.

6.5 Monolithic Form Work — This is practically a slip form work for continuous use. This type of form work is only suitable for a circular or near circular tunnel when the lining of full section is done in one operation. This type of form work may be suitable in steeply inclined tunnels/shafts.

6.6 General Requirement of Forms — All form work should have inspection windows about 50 × 30 cm in size and not more than 3 m apart. Horizontal and vertical intervals of spacings will depend on the size and shape of tunnel, thickness of lining, method of placement and workability of concrete. The aim shall be to eusure dense compact concrete. These windows are used to place and vibrate the concrete. The shutters to these should be strong and easily operable and fitting well as not to permit cement slurry to flow out or to leave projections in the finished concrete surface. Flexible shaft internal type vibrators may be used through these windows.

6.6.1 All forms, except where continuous non-stop concreting is adopted, require provision of a bulk head shuttering at the other end where use of timber is generally convenient. The bulk head is necessary to make a neat construction joint.

7. BATCHING AND MIXING PLANT

7.1 In large tunnel lining jobs, it is necessary to use batching and mixing plants to manufacture concrete for lining. Depending on the size of tunnel and equipment available, the concrete may be mixed in a standard batching and mixing plant outside the tunnel and the mixed concrete taken to site of placement or the aggregates batched and mixed dry outside and taken to site of placement inside the tunnel and mixed with water inside the tunnel. It is advisible to add cement also inside to avoid its setting as the aggregates are aften wet or moist. Except in small or very short tunnels, the concrete placer or concrete pump shall be inside the tunnel, near the site of lining. In large tunnels especially long ones, wherever it is possible and convenient, taking the mixing and batching plants also inside the tunnel is advisable.

8. TRANSPORTING CONCRETE OR DRY MIXED AGGREGATES

8.1 For tunnels of short length and where comparatively large volumes of concrete are required, concrete is generally mixed in a batching plant located at a suitable site outside the tunnel, and the mixed concrete conveyed as quickly as possible to the site of placement by means of short belt conveyors, agitator cars, truck mounted mixers, etc, and poured into the hopper of the concrete pump or placer kept close to the location of concreting. This has a disadvantage that as the time of transportation increases, the quality of concrete tends to get affected through over-mixing in the case of agitator cars and truck mounted mixers and a certain amount of initial set may take place before actual placement.

8.2 For tunnels of comparatively longer lengths, it is advantageous to batch and mix the concrete in dry condition outside the tunnel and then convey the same inside the tunnels to locations of placement by means of tipping wagons or dumpers. The dry mixed aggregates are then remixed at site adding the required quantity of cement and water to obtain the specified slump and water cement ratio. The aggregates should be as dry as possible when mixed outside. The mixer for mixing at site of placement has to be so located that the dry mixed aggregates can be easily dumped into the hopper of the mixer and the mixed concrete pouring out of it can fall into the hopper of the placer or pump. Suitable retarders may be used where ready mixed concrete is transported in transit cars. In case of vertical shafts used as construction adit, mixed concrete can be conveyed through 'elephant trunks'. These 'trunks' should be made up of short tapered pieces linked to each other. The drop from the bottom of the 'trunk' to the concrete heap below shall not be more than 1 m.

9. PLACING CONCRETE

9.1 If the invert concreting or kerb concreting is done first, the surface of old concrete shall be covered by 25 mm thick layer of mortar (of the same mix as the concrete, without coarse aggregate) to get a proper bond with the new concrete. During concreting by a pump or a placer behind form work for sides and arch, if the placing is interrupted for a period of more than one hour, a batch (sufficient to cover the area by a 15 mm layer) of mortar as above shall be pumped to cover the cold joints.

9.1.1 Care shall be taken while pouring through side doors in forms so that no hollow pockets remain. In the case of monolithic forms, as the concrete will fill the invert first, there may be a tendency for the form to float, and therefore the form shall be strutted down rigidly from the sides and the roof of the tunnel as well.

9.1.2 The concrete may be placed either by a concrete pump or pneumatic placer. Concrete in the invert may be placed direct. The discharge end of the concrete delivery pipe may be ke buried a few centimetres inside the freshly placed concrete, as far as practicable, to avoid segregation. Pumps and especially placers are sensitive to the pressure of the compressed air supply. In case of long compressed air supply lines, air chambers of adequate capacity shall be provided on the pipe line near the discharge end to reduce pressure drop.

10. REINFORCEMENT

10.1 It is generally not necessary to provide any reinforcement in the lining in good rock [*see* IS : 4880 (Part IV) - 1971*]. Whenever it becomes

*Code of practice for design of tunnels conveying water: Part IV Structural design of concrete lining in rock.

necessary to provide reinforcement, sufficient cover shall be provided. The spacing of reinforcement shall be adequate to permit flow of concrete around it without any hollows anywhere.

11. CONSTRUCTION JOINT

11.1 Two types of construction joints generally become necessary namely, (a) bulk head and (b) longitudinal.

11.1.1 Bulk head joints are required to be provided at the end of each shutter.

11.1.2 Longitudinal joints become necessary at the junction of the sides and the invert where the kerb becomes an integral part of either the invert or the sides. Where the kerbs are laid separately, there will be two such joints at each kerb. When the sides and arch are laid separately similar joints become necessary at sides and arch. No special treatment is necessary for such construction joints except general cleaning and, where applicable, a layer of cement sand mortar as specified in **9.1** may be laid on the joint.

12. CONSOLIDATION

12.1 As far as possible, flexible shaft immersion type vibrators having a vibrating needle of 50 mm dia and 8 000 vibrations/min frequency should be used for vibration of concrete (*see* IS : 2505-1968*). In addition the concrete shall be vibrated by external form vibrators of minimum 0·5 kW capacity. The spacing of form vibrators depends on the size of vibrator, mass of form work, thickness of concrete, etc. The spacing shall be adequate to ensure satisfactory compaction. The vibrator spacing shall be closer at the crown portion.

13. CURING

13.1 Curing may be generally done by spraying water at short intervals to maintain a wet surface. Strong draft of wind shall be avoided through the tunnel to reduce chances of sudden drying and consequent cracking.

14. GROUTING

14.1 Concrete lining of underground works shall be grouted to pack the hollow space (gaps) between rock and concrete lining. Grouting shall be done under flow pressure not exceeding 5 kg/cm^2 or as required depending on the circumstances. The pattern and spacing of the holes shall be decided in accordance with IS : 5878 (Part VII)-1972†. Where grout intake indicates gap of more than 10 mm, very fine sand or rock dust should be added to the grout to fill the gap. In certain locations addition of bentonite may be helpful to hold cement in suspension for satisfactory grouting. The grout pressure should be reduced adequately when contact grouting in crown portion is done before invert is laid.

*Specification for concrete vibrators, immersion type (*first revision*).

†Code of practice for construction of tunnels conveying water: Part VII Grouting.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones: 331 01 31, 331 13 75 — Telegrams: Manaksanstha (Common to all Offices)

Regional Offices:	*Telephone*
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
*Eastern : 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola, CALCUTTA 700054	36 24 99
Northern : SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43 3 16 41
Southern : C. I. T. Campus, MADRAS 600113	41 24 42 41 25 19 41 29 16
†Western : Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95
Branch Offices:	
'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48 2 63 49
‡Peenya Industrial Area 1st Stage, Bangalore Tumkur Road BANGALORE 560058	38 49 55 38 49 56
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	6 67 16
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
53/5, Ward No. 29, R.G. Barua Road, 5th Byelane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg (Nampally Station Road), HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71 6 98 32
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76 21 82 92
Patliputra Industrial Estate, PATNA 800013	6 23 05
T.C. No. 14/1421, University P.O., Palayam TRIVANDRUM 695035	6 21 04 6 21 17
Inspection Offices (With Sale Point):	
Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	2 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office in Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, Calcutta 700072 — 27 68 00

†Sales Office in Bombay is at Novelty Chambers, Grant Road, Bombay 400007 — 89 65 28

‡Sales Office in Bangalore is at Unity Building, Narasimharaja Square, Bangalore 560002 — 22 36 71

Reprography Unit, BIS, New Delhi, India

IS 5878-6 (1975): Code of practice for construction of tunnel conveying water, Part 6: Steel lining [WRD 14: Water Conductor Systems]

BLANK PAGE

(Reaffirmed 2000)

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART VI STEEL LINING

(Third Reprint NOVEMBER 1991)

UDC 624.191.2:624.191.835

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3

June 1975

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART VI STEEL LINING

Water Conductor Systems Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE
Ramalayam, Peddar Road
Bombay 400026

Members	*Representing*
ADDITIONAL DIRECTOR (FE)	Ministry of Railways, New Delhi
DEPUTY DIRECTOR STANDARDS (B & S)-I (*Alternate*)	
SHRI S. P. BHAT	Public Works & Electricity Department, Government of Karnataka, Bangalore
SHRI K. R. NARAYANA RAO (*Alternate*)	
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhra Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (DESIGN & PLANNING) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
SHRI K. RAMABHADRAN NAIR (*Alternate*)	
CHIEF ENGINEER (Irrigation)	Public Works Department, Government of Tamil Nadu, Madras
SUPERINTENDING ENGINEER (D&WC) (*Alternate*)	
SHRI O. P. DATTA	Beas Designs Organization, Nangal Township
SHRI J. S. SINGHOTA (*Alternate*)	
DIRECTOR (HCD)	Central Water & Power Commission, New Delhi
DEPUTY DIRECTOR (PH-1) (*Alternate*)	
DIRECTOR, LRIPRI	Irrigation & Power Department, Government of Punjab, Chandigarh
SHRI H. L. SHARMA (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
SHRI R. G. GANDHI	Hindustan Construction Co Ltd, Bombay
SHRI R. K. JOSHI (*Alternate*)	
SHRI K. C. GHOSAL	Alokudyog Services Ltd, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI M. S. JAIN	Geological Survey of India, Calcutta
SHRI L. N. KABIRAJ	Damodar Valley Corporation, Dhanbad
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra, Bombay
SHRI S. M. BHALERAO (*Alternate*)	
SHRI D. N. KOCHHAR	National Projects Construction Corporation Ltd, New Delhi
SHRI K. N. TANEJA (*Alternate*)	
SHRI Y. G. PATEL	Patel Engineering Co Ltd, Bombay
SHRI C. K CHOKSHI (*Alternate*)	
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SECRETARY	Central Board of Irrigation & Power, New Delhi
DEPUTY SECRETARY (I. O.) (*Alternate*)	
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh, Lucknow
SHRI D. AJITHA SIMHA, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

SHRI K. K. SHARMA
Assistant Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra, Bombay
Members	
ADDITIONAL DIRECTOR (FE)	Ministry of Railways, New Delhi
DEPUTY DIRECTOR STANDARDS (B & S)-I (*Alternate*)	
SHRI C. K. CHOKSHI	Patel Engineering Co Ltd, Bombay
DEPUTY DIRECTOR (HCD)	Central Water & Power Commission, New Delhi
SHRI K. C. GHOSAL	Alokudyog Services Ltd, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI R. K. JOSHI	Hindustan Construction Co Ltd, Bombay
SHRI D. G. KADKADE (*Alternate*)	
SHRI A. R. RAICHUR	R. J. Shah & Co Ltd, Bombay
SHRI G. L. RAMASWAMIAH	Indian Hume Pipe Co Ltd, Dehradun
SHRI S. A. VIJAYAKEERTI (*Alternate*)	
SHRI K. SHAMA RAO	Kerala State Electricity Board, Trivandrum
SHRI JOHN M. JOHN (*Alternate*)	
SHRI G. N. TANDON	Irrigation Department, Government of Uttar Pradesh, Lucknow

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART VI STEEL LINING

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 29 January 1975, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The construction of tunnels involves a large number of problems. Because of the great longitudinal extent of the work many different kinds of conditions are encountered which for maximum economy should be treated differently. This standard covers recommendations which would be generally applicable to construction of tunnels for the assistance of the engineers engaged in the project. This standard should, however, be used with caution since due to the very nature of the subject it is not possible to lay down detailed specifications to cover each and every possible case. The specifications laid down by designers shall be followed and the discretion of the engineer-in-charge would be required in some cases.

0.3 Lining of tunnels generally contributes to the total cost of the tunnel to an extent of 30 to 40 percent, and therefore, lining operation requires considerable study and careful planning.

0.3.1 The type of lining chosen for tunnels depends upon the quality of the rock and the type of tunnel. Tunnels forming part of a water conductor system have to be invariably lined with cement concrete from structural and hydraulic considerations. If the tunnel has to withstand very high internal pressures, it will have to be steel lined.

0.4 This standard is being published in parts. Other parts of this standard are as follows:

Part I Precision survey and setting out

Part II Underground excavation in rock

Section 1 Drilling and blasting

Section 2 Ventilation, lighting, mucking and dewatering

Section 3 Tunnelling method for steeply inclined tunnels, shafts and underground power houses

Part III Underground excavation in soft strata

Part IV Tunnel supports

Part V Concrete lining

Part VII Grouting

0.5 Other related standards are given below:

IS : 2825-1969 Code for unfired pressure vessels

IS : 4081-1967 Safety code for blasting and related drilling operations

IS : 4137-1967 Safety code for working in compressed air

IS : 4756-1968 Safety code for tunnelling work

IS : 4880(Part II)-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880(Part III)-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4880(Part IV)-1971 Code of practice for design of tunnels conveying water: Part IV Structural design of concrete lining in rock

IS : 4880(Part V)-1972 Code of practice for design of tunnels conveying water: Part V Structural design of concrete lining in soft strata and soils

IS : 4880(Part VI)-1971 Code of practice for design of tunnels conveying water: Part VI Tunnel supports

0.6 This standard does not cover the design of steel lining for tunnels. The design aspects are covered in IS : 4880 (Part VII)-1975*.

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This code of practice covers fabrication, testing and erection of steel lining of tunnels conveying water from reservoirs to hydraulic turbines in hydro-power plants or *vice-versa* in case of reversible pump turbines in pumped storage schemes or for other similar installations.

*Code of practice for design of tunnels conveying water: Part VII Steel lining.

†Rules for rounding off numerical values (*revised*).

1.2 This code of practice does not cover fabrication, testing and erection of specials like bends, bifurcations, etc.

2. MATERIALS

2.1 The material to be used for different components shall be as given in **2.1.1** to **2.1.4**.

2.1.1 Steel plates for liners, nozzle attachments and all pressure parts shall be of weldable boiler quality plates conforming to Grade I or Grade 2A of IS: 2002-1962*. These plates shall come under carbon steels of minimum tensile strength of 28 to 53 kg/mm². High tensile steel, low alloy steel, etc, may be used provided proper welding procedure is established for the use of such steel. Where high heads are involved, the use of high tensile steel conforming to IS : 2041-1962† is recommended.

2.1.2 The stiffeners may be cut from plates or structurals bent to the required shape. The material shall conform to the requirements of IS : 226-1969‡.

2.1.3 Gaskets for manholes or other flanged nozzles shall be of compressed asbestos fibre suitable for the purpose and temperature of the working conditions. If rubber ring is used, the hardness of the rubber ring shall be Durometer 75 ± 5.

2.1.4 Welding consumables such as electrodes, filler rods and wires shall conform to IS: 814 (Part II)-1974§, IS : 1395-1971||, IS : 3613-1966¶, IS : 6419-1970**, IS : 6560-1972†† and IS : 7280-1974‡‡.

3. FABRICATION

3.1 General

3.1.1 Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure welds which will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly. For this purpose

*Specification for steel plates for boilers.

†Specification for steel plates for pressure vessels.

‡Specification for structural steel (standard quality) (*fourth revision*).

§Covered electrodes for metal arc welding of structural steels: Part II For welding sheets (*fourth revision*).

||Specification for molybdenum and chromium molybdenum vanadium low alloy steel electrodes for metal-arc welding (*second revision*).

¶Acceptance tests for wire flux combinations for submerged arc welding.

**Welding rods and bare electrodes for gas shielded arc welding of structural steels.

††Molybdenum and chromium molybdenum low alloy steel welding rods and bare electrodes for gas shielded arc welding.

‡‡Bare wire electrodes for submerged arc welding of structural steels.

reference may be made to IS : 7307 (Part I)-1974* and IS : 7310 (Part I)-1974†.

3.1.2 No production work shall be undertaken until both the welding procedure and the welders or welding operations have been approved.

3.1.3 *Forming Shell Sections and Tolerance* — All plates for shell sections shall be formed to the required shape by any process that will not unduly impair the physical properties of the material. The formed shell section shall conform to the tolerances given in **3.1.3.1** to **3.1.3.3**.

3.1.3.1 The formed section shall be substantially circular in cross-section. The measured circumference at any cross-section shall not be less than the calculated circumference and shall not exceed the calculated circumference by more than 10 mm.

3.1.3.2 The difference between the maximum and minimum diameter at any cross-section shall not exceed one percent of the nominal diameter at the cross-section under consideration subject to a maximum of 10 mm.

3.1.3.3 The ends of each shop fabricated shell section (pipe) shall be in a plane normal to the longitudinal axis of the section with a maximum deviation of 2 mm on either side of the plane.

3.2 Welding Process — The welding process to be adopted in the construction of liners shall be restricted to the following:

a) Manual metal arc,

b) Submerged arc, and

c) Metal inert gas arc.

3.2.1 The welding procedure adopted shall conform to IS : 823-1964‡ and IS : 4353-1967§.

3.2.2 Where the weld metal is deposited in successive layers, each layer shall be thoroughly cleaned bofore the subsequent layer is deposited. Whenever possible, joints shall be welded in the flat position. Welded joints shall be reasonably free from craters, depressions and other irregularities. After welding is completed, all weld spatters shall be removed. Welded beads on the interior surfaces of the liner shall be corrected by grinding so as not to project more than 1·5 mm.

3.2.3 Field girth joints may be accomplished using back up bars if both side welding is not possible due to non-accessibility.

---

*Approval tests for welding procedures: Part I Fusion welding of steel.

†Approval tests for welders working to approved welding procedures: Part I Fusion welding of steel.

‡Code of procedure for manual metal arc welding of mild steel.

§Recommendations for submerged arc welding of mild steel and low alloy steel.

3.2.4 *Lowest Permissible Temperature for Welding* — It is recommended that no welding of any joint be done when the temperature of the base metal is lower than −18°C. At temperature between −18°C and 0°C the surface of all areas within 75 mm of the point where a weld is to be started should be heated to a temperature 15°C (that is, warm to hand) before welding is started. It is also recommended that no welding be done when surfaces are wet or covered with ice or during periods of high wind, unless the welders or welding operators and the work are properly protected.

3.2.5 All welds shall have complete penetration and shall be free from imperfections and all defective welds shall be repaired. Defects in the welds shall be chipped or flame gauged until sound metal is reached on all sides and the resulting cavity shall be filled by the same procedure as when the original grooves were filled. The test shall be repeated.

3.2.6 *Cutting, Fitting and Alignment*

3.2.6.1 Plates and other parts may be cut to shape and size by mechanical means or by oxy-acetylene cutting. When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be free from all loose scale and slag accumulations before welding.

3.2.6.2 Plates that are being welded shall be fitted, aligned and retained in position during the welding operation.

3.2.6.3 Bars, jacks, clamps, tack-welds or other appropriate means may be used to hole the edges to be welded in line. Tack welds may be used provided those in plates over 6 mm thick are removed by suitable means before welding the joints, so that these tack welds do not become part of the final joint.

3.2.6.4 The edges of butt joints shall be held during welding so that the tolerances are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerance, the shells ring shall be finished until the errors are within the limits specified.

3.2.7 *Cleaning of Surfaces to be Welded* — The surfaces to be welded shall be clean and free from foreign materials, such as grease, oil, lubricants and marking paints for a distance of at least 15 mm from the welding edge. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel or air chipping hammers or other suitable means so as to prevent inclusion of impurities on the weld metal.

3.2.8 Cast surfaces to be welded shall be machined, chipped or ground to remove foundry scale and to expose sound metal.

3.3 Alignment Tolerance — Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the values given in Table 1.

TABLE 1 ALLOWABLE VALUES FOR MAXIMUM OFFSETS IN BUTT WELDING

(*Clause* 3.3)

Thickness t	Longitudinal Joints	Girth Joints
(1)	(2)	(3)
mm	mm	mm
Up to 12	1/4 t	1/4 t
Over 12 and up to 20	3 mm	1/4 t
Over 20 and up to 40	3 mm	5 mm
Over 40 and up to 50	3 mm	1/8 t
Over 50	Lesser of 1/16 t or 10 mm	Lesser of 1/8 t or 20 mm

3.4 Staggering of Joints — The longitudinal seams of adjoining course of liner section shall be staggered by at least five times the thickness of thicker plate. If, however, this is not possible 100 mm on either side of each welded inter-section shall be radiographed.

3.5 Bends — Bends shall be mitred with minimum radius of curvature three to five times the internal diameter of the pipe and included angle of maximum 10° between segments. The radius of curvature shall be referred to the centreline of the bend.

3.6 Stress Relieving — No stress relieving is required for joints in steel liners made up of plates of 32 mm or lesser thickness. Where thickness of the plates exceeds 32 mm but not 38 mm, the joints shall be preheated before welding. If thickness of steel plates exceeds 38 mm, stress relieving of joints shall be done in a furnace. Where this is not possible then stress relieving may be done by induction coil heating method.

3.7 Painting

3.7.1 All the surfaces requiring painting shall be sand/shot blasted according to accepted practices.

3.7.2 The inside surface of liner shall be protected against corrosion by painting with suitable paints selected to meet working and operating conditions of the pipes. The recommended paints are coal tar enamel/coal tar epoxy.

3.7.3 Surfaces in contact with concrete, after cleaning in accordance with **3.7.1** shall be coated with a thin film of cement slurry to protect against corrosion and for proper bondage with concrete.

4. TESTS AFTER FABRICATION

4.1 The tests given in **4.1.1** to **4.1.3** shall be conducted after fabrication.

4.1.1 *Radiography* — All butt welded longitudinal joints shall be 100 percent X-rayed. Use of Gamma rays is recommended for thicker plates,

4.1.2 *Ultrasonic Tests* — All butt welded girth joints shall be 100 percent ultrasonically tested.

4.1.3 *Shop Hydraulic Tests* — All pipes of standard lengths shall be subjected to shop hydraulic test. Non-standard pipe and elbows can be tested as standard pipe before being cut to size. Hydraulic testing of longitudinal joints is mandatory.

4.1.3.1 The test pressure shall be calculated from the following formula:

$$P = \frac{2 f_t \cdot t}{D}$$

where

P = hydrostatic test pressure in kg/cm^2,

f_t = 0·8 yield stress in steel,

t = minimum thickness in centimetre of plate in liner length tested, and

D = maximum internal diameter in centimetre of section being tested.

4.1.3.2 In general, the shop test pressure shall ensure that the plate material is stressed to 80 percent of minimum yield strength and at least equal to one and half times the allowable working pressure.

4.1.3.3 Each liner length shall be filled with water and the pressure slowly and uniformally increased until the required test pressure is reached and held at that pressure until all welded joints are examined. Any defects in welds or plate disclosed by the hydrostatic test shall be repaired and all repaired sections shall be retested.

5. ERECTION OF STEEL LINERS

5.1 General — Installation of steel liners is an extension of fabrication procedure at site in conjunction with the construction of underground works like tunnels, powerhouse, surge tower, etc.

5.2 Construction of Rail Track — To facilitate erection of steel liners in position, a rail track should be laid inside the tunnel and also winch o suitable capacity installed. In case of vertical penstocks, instead of the track a platform is constructed with bridge arrangements to handle the pipes during erection.

5.2.1 The rail track is not considered as a permanent part of the work unless agreed between the parties in the contract since this is only an item to facilitate erection of the liners.

5.3 Installation of steel liners is taken up from the anchor blocks at the lowest or tail ends progressing upwards to surge tank. Steel liners could be installed over the tunnel lengths separately and both joined together at the junction.

5.4 Excavation of tunnels, surge, junction and other places where steel liners are to be installed should be done according to the relevant code of practice (*see* **0.4**). Loose scales have to be removed completely and there shall be no stretch with tightness which will infringe on the steel liners. In case of loose soft rock, adequate temporary supporting should be ensured with steel girders and backfill concrete and/or shot-creting which could be embedded in the final concrete. If temporary lining is done with material that cannot be burried in final concrete, the same has to be removed without fail. Major excavation being thus completed to full section, only spot tightness may be required to be removed during the actual installation of steel liners in position which could be done without much inconvenience.

5.5 Anchor Bolts — Anchor bolts shall be installed at the levels established as working bases for the installation of liners. The liners sections shall be located or placed in position in accordance with erection diagram and shall be completely aligned to grade before the joints are welded and the sections are embedded in concrete. Necessary permanent structural steel supports, blocking cables, anchors or expansion spiders required to hold the liners in position or prevent distortion while the liners are being welded or being embedded in concrete, shall be provided in respective locations. When assembled and ready for welding the distance between ends of adjoining sections which are to be connected together with butt-welds shall not go greater than 6 mm and not less than 3 mm. Care shall be taken to avoid excessive increase or shrinkage in length. All welding and repairing of defective welds shall be performed according to the provisions detailed under fabrication. In case of penstock or other liners where the clearance all around is not adequate to accommodate welders to perform proper welding, welding is done from inside. The size of back up bar is minimum 75 × 12 mm. Double welded butt joints can be accomplished if space around is 0·6 m or more. After the given joints are welded and repaired where required according to the specification the sections are cleaned and are ready for being encased in concrete.

5.6 Concreting — Liners are encased in concrete — concreting being done generally by pneumatic placement. Concreting is done generally over lengths at a stretch up to 6 to 7·5 m for smoother and economical operations to minimize interruptions in the installation of pipes and welding them which is the major work in the whole procedure.

5.7 Grouting — Grouting should be done behind the concrete lining to fill up the shrinkage gap between the rock and concrete and concrete and steel liner if any to make the whole mass monolith with the parent rock. Grouting has also to be done in the rock all around to fill up the pores, fissures in

rock mass to prevent building up of hydrostatic pressure and to strengthen the rock all around in general. Grouting shall be done in accordance with IS : 5878 (Part VII)-1972*.

5.7.1 For grouting, holes are provided in the liner generally 3 numbers on periphery or at every 3 m arc length whichever is more staggered in alternate ferrules. The holes drilled in plate steel liners shall be plugged; alternatively holes may be closed by plug welding after completion of grouting. The plug weld shall be ground flush with the liner surface.

5.7.2 While drilling such holes utmost care shall be taken to ensure that the anchor rods or stiffeners behind the plate steel liner or reinforcement, if any, in case of concrete lining shall not be cut through.

6. BASIS OF MEASUREMENT

6.1 All items which form permanent part of the steel lining work including supports, struts between rocks and steel liner, grout plugs, backup bars, stiffeners, etc, shall be measured for payment.

6.2 The basis shall be theoretical weight plus half of maximum provided tolerance in accordance with IS : 2002-1962†.

---

*Code of practice for construction of tunnels : Part VII Grouting.
†Specification for steel plates for boilers.

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones: 331 01 31, 331 13 75 — Telegrams: Manaksanstha (Common to all Offices)

Regional Offices:		*Telephone*
Central	Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
*Eastern	1/14 C. I. T. Scheme VII M. V. I. P. Road, Maniktola, CALCUTTA 700054	36 24 99
Northern	SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43 3 16 41
Southern	C. I. T. Campus, MADRAS 600113	41 24 42 41 25 19 41 29 16
†Western	Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95

Branch Offices:	
'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48 2 63 49
‡Peenya Industrial Area 1st Stage, Bangalore Tumkur Road BANGALORE 560058	38 49 55 38 49 56
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	6 67 16
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
53/5, Ward No. 29, R.G. Barua Road, 5th Byelane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg (Nampally Station Road), HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71 6 98 32
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76 21 82 92
Patliputra Industrial Estate, PATNA 800013	6 23 05
T.C. No. 14/1421, University P.O., Palayam TRIVANDRUM 695035	6 21 04 6 21 17

Inspection Offices (With Sale Point):	
Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	2 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office in Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, Calcutta 700072 — 27 68 00

†Sales Office in Bombay is at Novelty Chambers, Grant Road, Bombay 400007 — 89 65 28

‡Sales Office in Bangalore is at Unity Building, Narasimharaja Square, Bangalore 560002 — 22 36 71

Reprography Unit, BIS, New Delhi, India

AMENDMENT NO. 1 MARCH 1977

TO

IS:5878(Part VI)-1975 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

PART VI STEEL LINING

Alteration

(First cover page, pages 1 and 3, title) - Substitute the following for the existing title:

'*Indian Standard*
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART VI STEEL LINING'

(BDC 58)

IS 5878-7 (1972): Code of practice for construction of tunnels conveying water, Part 7: Grouting [WRD 14: Water Conductor Systems]

BLANK PAGE

REAFFIRMED 2005

Indian Standard
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER
PART VII GROUTING

Fourth Reprint JUNE 1993
(Incorporating Amendment No. 1)

UDC 624.191.2:666.97.033.14

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 4 May 1973

Indian Standard
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER
PART VII GROUTING

Water Conductor Systems Sectional Committee, BDC 58

Chairman

SHRI P. M. MANE
Ramalayam, Pedder Road, Bombay 26

Members	*Representing*
SHRI K. BASANNA	Public Works Department, Government of Mysore
SHRI N. M. CHAKRAVORTY	Damodar Valley Corporation, Dhanbad
CHIEF CONSTRUCTION ENGINEER	Tamil Nadu Electricity Board, Madras
SUPERINTENDING ENGINEER (TECHNICAL/CIVIL) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Andhra Pradesh State Electricity Board, Hyderabad
SUPERINTENDING ENGINEER (CIVIL AND INVESTIGATION CIRCLE) (*Alternate*)	
CHIEF ENGINEER (CIVIL)	Kerala State Electricity Board, Trivandrum
CHIEF ENGINEER (IRRIGATION)	Public Works Department, Government of Tamil Nadu
SHRI J. WALTER (*Alternate*)	
DIRECTOR (HCD)	Central Water & Power Commission, New Delhi
DEPUTY DIRECTOR (PH-I) (*Alternate*)	
DIRECTOR, LRIPRI	Irrigation & Power Department, Government of Punjab
SHRI H. L. SHARMA (*Alternate*)	
SHRI O. P. DATTA	Beas Designs Organization, Nangal Township
SHRI J. S. SINGHOTA (*Alternate*)	
SHRI D. N. DUTTA	Assam State Electricity Board, Shillong
SHRI R. G. GANDHI	Hindustan Construction Co Ltd, Bombay
SHRI M. S. DEWAN (*Alternate*)	
SHRI K. C. GHOSAL	Alokudyog Cement Service, New Delhi
SHRI A. K. BISWAS (*Alternate*)	
SHRI M. S. JAIN	Geological Survey of India, Calcutta
SHRI I. P. KAPILA	Central Board of Irrigation & Power, New Delhi
SHRI B. S. KAPRE	Irrigation & Power Department, Government of Maharashtra

(*Continued on page* 2)

(Continued from page 1)

Members	*Representing*
Shri Y. G. Patel	Patel Engineering Co Ltd, Bombay
Shri C. K. Chokshi (*Alternate*)	
Shri A. R. Raichur	R. J. Shah and Co Ltd, Bombay
Shri S. Ramchandran	National Projects Construction Corporation Ltd, New Delhi
Shri K. N. Taneja (*Alternate*)	
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh
Shri D. Ajitha Simha, Director (Civ Engg)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri G. Raman

Deputy Director (Civ Engg), ISI

Panel for Construction of Tunnels, BDC 58 : P2

Convener	
Shri B. S. Kapre	Irrigation & Power Department, Government of Maharashtra
Members	
Shri C. K. Chokshi	Patel Engineering Co Ltd, Bombay
Deputy Director (PH-I)	Central Water & Power Commission, New Delhi
Shri M. S. Dewan	Hindustan Construction Co Ltd, Bombay
Shri K. C. Ghosal	Alokudyog Cement Service, New Delhi
Shri A. K. Biswas (*Alternate*)	
Shri A. R. Raichur	R. J. Shah and Co Ltd, Bombay
Shri G. L. Ramaswamiah	Indian Hume Pipe Co Ltd, Dehradun
Shri S. A. Vijayakeerti (*Alternate*)	
Shri K. Shama Rao	Kerala State Electricity Board, Trivandrum
Shri A. S. Naraynan (*Alternate*)	
Shri G. N. Tandon	Irrigation Department, Government of Uttar Pradesh

AMENDMENT NO. 2 JANUARY 2008
TO
IS 5878 (PART 7) : 1972 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART 7 GROUTING

(*Page* 3, *clause* **0.4**) — Substitute 'IS 6066' *for* 'IS 6066 : 1971 Recommendation for pressure grouting of rock foundation in river valley projects'.

(*Page* 4, *clause* **0.6**) — Delete.

(*Page* 4, *clause* **0.7**) — Substitute '**0.6**' *for* '**0.7**'.

(*Page* 4, *clause* **1**) — Insert the following clause after **1** and renumber the subsequent clauses:

2 REFERENCES

2.1 The following standards contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent additions of the standards indicated in below:

IS No.	*Title*
269 : 1989	Specification for 33 Grade ordinary Portland cement (*fourth revision*)
455 : 1989	Specification for Portland slag cement (*fourth revision*)
1344 : 1981	Specification for calcined clay pozzolana (*second revision*)
1489 (Part 1) : 1991	Specification for Portland pozzolana cement: Part 1 Flyash based (*third revision*)
3812 : 1981	Specification for flyash for use as pozzolana and admixture (*first revision*)

IS No.	*Title*
5878 (Part 6) : 1975	Code of practice for construction of tunnels: Part 6 Steel lining
6066 : 1994	Recommendation for pressure grouting of rock foundation in river valley projects.
8112 : 1989	Specification for 43 grade ordinary Portland cement (*first revision*)
12269 : 1987	Specification for 53 grade ordinary Portland cement (*first revision*)

2.2 The reference to Indian Standards, wherever mentioned in this Code, shall be as per clause **2.1**.

(*Page* 12, *clause* **6.3.5**, *second sentence*) — Substitute '**7.3.2**' *for* '**7.3.1**'.

(*Page* 14, *clause* **7.3.1**) — Substitute the following for the existing:

'**7.3.1** Grouting should be done with cement conforming to IS 269 or IS 8112 or IS 12269 or IS 455 or IS 1489 (Part 1) as specified by the Engineer-in-Charge.'

(*Page* 14, *clause* **7.3.4**, *second sentence*) — Substitute the following for the existing:

'If intake is heavy, the grout may be thickened by incorporation of pozzolana such as flyash conforming to IS 3812 or calcined clay conforming to IS 1344 in the mix or by using inert material like fine sand, rock powder, clay or bentonite.'

(WRD 14)

Reprography Unit, BIS, New Delhi, India

Indian Standard
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART VII GROUTING

0. FOREWORD

0.1 This Indian Standard (Part VII) was adopted by the Indian Standards Institution on 29 December 1972, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The treatment of rock around the tunnel bore, and the treatment of the plane of contact between the rock and concrete lining and of the contact plane between concrete and steel lining in tunnels, by pressure grouting is a very important aspect of the construction of tunnels, as the design of lining is based on properly executed grouting of the rock and the contact zones. The success of the grouting depends upon a co-ordinated handling of the work of exploration, initial trials, field control and testing.

0.3 It has been appreciated that it would not be appropriate to stipulate rigid standards to meet the various uncertain and diverse conditions that are met with in underground works. The aim of these recommendations is to summarize the commonly used procedures, equipment and technique in order to enable the Engineer-in-Charge of the job to evolve a procedure suited to the particular job and to achieve the degree of stabilization required by the designs by a process of experimentation on the proper lines.

0.4 This standard covers special features for grouting used for tunnels only. However, for foundation grouting a reference may be made to IS : 6066-1971*.

0.5 The other parts of this standard are as follows:

Part I	Precision survey and setting out
Part II	Underground excavation in rock
Part III	Underground excavation in soft strata
Part IV	Tunnel supports
Part V	Concrete lining
Part VI	Steel lining

*Recommendations for pressure grouting of rock foundations in river valley projects.

0.6 This standard is one of a series of Indian Standards on tunnels. Other standards published so far in the series are the following:

IS : 4081-1967 Safety code for blasting and related drilling operations

IS : 4137-1967 Safety code for working on compressed air

IS : 4756-1968 Safety code for tunnelling work

IS : 4880 (Part II)-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880 (Part III)-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4880 (Part IV)-1971 Code of practice for design of tunnels conveying water: Part IV Structural designs of concrete lining in rock

IS : 4880 (Part VI)-1971 Code of practice for design of tunnels conveying water: Part VI Tunnel supports

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the results of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This code gives recommendations regarding pressure grouting for tunnels primarily using cement with or without suitable admixtures. Chemical grouting is not dealt with in detail as the properties of chemical grouts as well as the techniques adopted vary from place to place to meet the special localized conditions of the job.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following terminology shall apply.

2.1 Backfill Grouting — Due to the irregular excavated section of the rock, empty pockets are left behind the concrete in the lining in the arch portion of a tunnel or a cavity. Backfill grouting is the process of filling these spaces by sand-cement grout.

*Rules for rounding off numerical values (*revised*).

2.2 Circulating System — The piping arrangement by which grout is conveyed from the grout pump to the grout hole and through a return line from the hole to the grout tank.

2.3 Consolidation Grouting — The process of pressure grouting to fill up voids in rock or to consolidate the rock mass around the periphery of the bore, generally to a uniform distance from the finished surface of the concrete lining. This is done under relatively high pressures.

2.4 Contact Grouting or Pack Grouting — The process of grouting behind the concrete lining or steel liner, to fill up the shrinkage gap and voids, if any, between the concrete lining and the rock surface and/or between the steel liner and the concrete behind it.

2.5 Manifold or Header — The piping arrangement at the mouth of the hole for connecting the supply/return lines to the hole being grouted.

2.6 Packer — A devise used in a hole to segregate a part of the hole to be grouted from the remaining length of the hole.

2.7 Grouting Pattern — An arrangement of holes for grouting.

2.8 Pressure Testing — The process of pumping water into a hole through a direct connection or a packer to measure the rate of acceptance of water under pressure (sometimes also referred to as water testing).

2.9 Single Line System — The piping arrangement by which grout is conveyed from a grout pump to the grout hole through a single line, there being no provision for a return line as in the circulating system.

2.10 Single Stage Grouting — The process of grouting the entire depth of the hole, drilled to the final designed depth, in one operation.

2.11 Stage — A complete operational cycle of drilling cleaning/washing, pressure testing (as may be required) and pressure grouting.

2.12 Stage Grouting — A grouting operation in which the hole is drilled and grouted in stages, redrilling through set grout if unavoidable, instead of being drilled to the entire depth and then grouted either in one operation as in single stage grouting, or in different operations using packers.

2.13 Umbrella Grouting — This is grouting from the face of the excavation in a pattern resembling a half opened umbrella, to consolidate the rock prior to excavation.

3. GENERAL

3.1 Grouting is carried out to fill discontinuities in the rock by a suitable material so as to improve the stability of the tunnel roof or to reduce its

permeability or to improve the properties of the rock. Grouting is also necessary to ensure proper contact of rock face of the roof with the lining. In such cases the grouting may be done directly between the two surfaces or the process of grouting may be used to fill the voids in the rubble packing where used. All the three types of grouting may not be required in all cases. The grouting procedures should aim at satisfying the design requirements economically and in conformity with the construction schedules. The basic design requirement generally involve the following:

a) Filling up the voids, cavities, between the concrete lining and rock and/or between the concrete and steel liner;
b) Strengthening the rocks around the bore by filling up the joints in the rock system;
c) Strengthening the rock shattered around the bore;
d) Strengthening the rock, prior to excavation by filling of the joints with cementing material and thus improving its stability; and
e) Closing up water bearing passages to prevent the flow of water into the tunnel and/or to concentrate the area of seepage into a channel from where it can be easily drained out.

3.2 Before drawing up the specifications for grouting the design requirements shall be established. In general for all underground structures, grouting is an universal requirement for all concrete lined tunnels. Design requirements are only to establish the maximum allowable pressure at which this grouting is to be carried out and the zone in the cross-section and the spacing of grout holes, both in the direction of the tunnel. For consolidation grouting the design requirement to be established is the thickness of the rock stratum around the bore that is to be strengthened and made impermeable, the pressure and the spacing pattern of holes. This will determine the depth to be grouted.

3.3 For tunnels, the commonly used procedures are to continue grouting to refusal at the design pressure in each hole or to interrupt the grouting if there is heavy intake with little or no pressure build up, indicating a very open structure and escape of grout to a long distance.

4. PATTERN, DEPTH AND ARRANGEMENT OF HOLES

4.1 Backfill Grouting

4.1.1 The purpose of backfill grouting is to fill the spaces left unfilled with concrete between the concrete lining and the rock surface in the arch portion of any tunnel or cavity.

4.1.2 Backfill grouting should be done after the concrete in lining has gained strength. This period of waiting may be from 21 to 28 days. In

case of precast lining segments this restriction of waiting will not apply and the grouting may be done immediately after the segments are erected.

4.1.3 Backfill grouting is limited to the arch portion of a tunnel or cavity and is not required in case of shafts if the concrete is poured vertically.

4.1.4 The grout holes at the crown should be placed 5 to 10 degrees from the crown, alternately in the left and right of the crown. In addition to the crown hole there shall be two more holes, one on either side of the crown. These holes will be 90° apart and will be located such that one of these two holes is at 22½° from the crown being alternately on the right and left of the crown. Such sections shall be normally 3 m apart. The exact location of the holes may be varied or additional holes provided depending upon the actual excavation profile at any section. The exact spacing of sections may also be varied on similar considerations. It should, however, be also adjusted to suit the length of the arch shutter used in such a way that there is no hole at the joint and the normal pattern of holes is more or less uniform in the shutter length.

4.1.4.1 In the case of circular or horse-shoe tunnels, in addition to these holes, two holes (one on either side), located roughly at 45 degrees on either side of the invert should be used. The location should be such that the holes are about 45 to 60 cm, above the junction of the invert and arch.

4.1.5 The mortar used for backfill grout shall normally consist of cement, sand and water mixed in the proportion of 1 : 1 : 1 by weight. It may, however, be suitably modified if site conditions so warrant. The size and grading of sand should be determined for each job by actual experimentation as it would depend on the type of sand and equipment available.

4.1.6 Backfill grouting should normally be done at a pressure of 2 kg/cm^2.

4.2 Contact Grouting

4.2.1 The aim of contact grouting is to fully pack up the space between the concrete lining and the rock surface or the space between the steel liner and concrete lining caused by shrinkage or left unfilled even after backfill grouting. This is required for fulfilling the design assumption of the rock/concrete taking part of the load along with the lining and to prevent local accumulation of water, if any, and building up local pressures.

4.2.2 Contact grouting should be done after the concrete lining has gained strength to withstand the pressure and shrinkage, if any, has taken place. The usual minimum period of 25 to 28 days of waiting should be allowed.

4.2.3 The contact grouting should be limited to only the top arch (90° on either side of the crown) of tunnels. In case of vertical shafts and steel liner, contact grouting should be done along the full periphery. In case of steel liners, the grouting should be done usually at specific points as is recommended in the ' Indian Standard code of practice for construction of tunnels: Part VI Steel lining ' (*under preparation*)*.

NOTE — Until the standard under preparation is published the details of grouting in case of steel liners are left to the discretion of the Engineer-in-Charge.

4.2.4 The holes at the crown shall be placed 5 to 10 degrees from the crown, being alternately to the left and right of the crown. In addition to the crown hole, there shall be two more holes one on either side of the crown in each section. These holes will be 90° apart and will be located such that one of the two holes is at 22½° from the crown, being alternately on the right and left of the crown. Such holes shall normally be 3 m apart.

4.2.4.1 In the case of circular or horse-shoe tunnels, in addition to these holes, two holes (one on either side), located roughly at 45 degrees on either side of the invert should be used. The location should be such that the holes are about 45 to 60 cm above the junction of the invert and arch.

4.2.5 The depth of holes for contact grouting shall be such that at each location, the holes extend 30 cm beyond the concrete lining into rock.

4.3 Consolidation Grouting

4.3.1 The aim of consolidation grouting is to fill up the joints and discontinuities in the rock up to the desired depth.

4.3.2 Consolidation grouting shall always be done after the backfill grouting is completed in a length of at least 60 m ahead of the point of grouting.

4.3.3 Consolidation grouting should be usually done all round the bore, and for a uniform radial distance from the finished concrete face. The depth of the holes to be drilled which determine the depth of the rock to be grouted should be determined by the designer based on the design of the concrete lining and the extent to which cracks are assumed to extend in rock when the lining is stressed by internal pressure. Usually the depth should be between 0·75 D and D where D is the finished diameter of the tunnel, except in special reaches where it could be more.

NOTE — The maximum depth so far used in the country is about 15 m.

4.3.4 The pattern of grout holes for consolidation may be a set of holes in one vertical plane, such a plane being called the grout plane. The spacing of the grout planes will depend upon the structural formation of rock and the travel of grout at the specified pressure. The exact spacing

*Since printed as IS : 5878 (Part VI) - 1975

as in the case of contact grouting should also be adjusted in the field to suit the length of the shutter used for concreting. In this plane the number of holes may normally be 4 for small size tunnels, and 6 for large size tunnels. The arrangement should be staggered in alternate grout planes, by about half the spacing between the holes along the periphery in the plane. In special locations the number of holes may be increased. The top three holes in grout pattern may be used for both backfill, contact and consolidation grouting.

4.3.5 Around shafts and large opening like powerhouse, the grout pattern will be similar, but the number of holes in the plane may be increased depending on the size, but the spacing should not generally exceed the depth of the hole.

4.3.6 Contact grouting would not generally be necessary where consolidation grouting had been done. However, it should be decided by actual contact grouting in jump holes after consolidation grouting.

4.3.7 Depending upon the rock formations and the grout intake, the consolidation grouting should be done in one or more stages with increasing pressures.

4.3.8 Maximum grout pressure should not normally exceed twice the design load on lining or supporting system as the case may be.

5. PRESSURE TO BE USED FOR GROUTING

5.1 The pressures to be used for grouting will depend on the rock characteristics, the design requirements and the rock cover. With adequate rock cover, (more than 3 times the diameter of the tunnel), the other two will govern. For backfill grouting the maximum pressure recommended is 5 kg/cm^2. For consolidation grouting a maximum pressure of 7·0 kg/cm^2 is normally recommended but this may be increased up to 20·0 kg/cm^2 in special cases provided that there is adequate cover and the joints in the rock are not likely to open up by this pressure.

5.2 The pressure gauge should be watched constantly so that the pressure on the grout is regulated as long as grouting is in progress. Any desired increase or decrease in the grouting pressure is obtained by changing the speed of the grout pump. When the grout in the supply line becomes sluggish, the grout-hole valve should be closed and the blow off valve is opened so that the supply line may be flushed or washed.

6. OPERATIONS

6.1 General — The process of grouting consists of the following operations:

a) Drilling holes,

b) Cleaning and washing holes,

c) Testing holes — pressure testing or water testing,
d) Grouting holes, and
e) Testing the grouted zone for efficacy of grouting.

6.2 Drilling — The size of holes to be drilled is generally decided by the depth of the hole to be drilled and the inclination of the holes. In all underground work, it is recommended that drilling through the lining should be avoided to the maximum extent possible. This is generally feasible since the general pattern is fixed before hand and black iron or galvanized pipes are placed in position while concreting. This ensures that the holes are located to the particular pattern and avoids unnecessary damage to concrete lining. It is very important that pipes are put in location of holes in the case of reinforced lining or where heavy steel supports are provided as this will avoid the expense of unnecessary trial holes that would have to drill to avoid drilling through reinforcement. A recommended method for guarding against the pipes getting filled up with concrete or mortar when concreting is to fill them solidly with moist earth just before these are fixed in position on the shutter. The usual nominal size of holes in underground works is 35 to 40 mm. The usual size of pipes embedded in concrete lining for drilling holes is 50 mm internal dia.

6.2.1 *Method of Drilling* — For pack grouting where the holes are drilled only to 15 cm in the rock, percussion drilling using an ordinary jack hammer is recommended. For consolidation grouting either percussion drilling or rotary drilling may be used. Rotary drilling is recommended where cores are required, and where the grouting has to be done using packers.

NOTE — With rotary drilling the EX size holes are usually adequate. Percussion drilling being faster and cheaper, is usually preferred. Percussion drilling cannot be done through clay, especially if the clay is moist and rotary drilling has to be used in such cases.

6.2.2 *Drilling Equipment* — The drilling equipment shall be capable of drilling holes of the required diameters and depths. It shall be operated by compressed air and should be equipped to provide for a continuous water or air flushing.

6.2.3 *Drilling Sequence* — It is preferable to drill a hole and grout it before drilling the adjoining hole in the same plane or in another plane since this will avoid the blocking of holes by the flow of grout if the adjoining holes are interconnected. However, if the construction schedule so requires and drilling is a time consuming part of the operation, the holes may be drilled in advance and a sequence evolved to avoid blocking of previously drilled holes to the maximum extent possible without too much movement of drilling rig. In case of pack grouting the side holes should be drilled and grouted first, before drilling and grouting the crown holes.

Depending on construction difficulties, for consolidation grouting, the drilling and grouting are recommended to be done from invert upwards doing the crown holes last. However, where the invert hole is exactly at the bottom and it cannot be drilled and grouted without interfering with other operations in the tunnels this should be done last.

6.3 Injection — Holes should be injected by direct connection to the grout pump. Each bore hole should be provided with a short standpipe threaded at the outer end to accept a manifold which should be provided with a pressure gauge, a relief valve and a valve enabling the delivery from the pump to be cut-off from the hole. A return grout line, equipped with a pressure relief valve can be set to open at any required pressure, may be connected to the manifold as a precaution against the application of excessive pressures. The return line should be led back to the mixing tanks in order to avoid unexpected discharge of grout into the working area. The valve for the return line may also be operated manually. When the pump discharge and pressure can be regulated at will in any desired combinations with compressed air operated pumps or pumps driven by a fluid under pressure, the use of return lines is not obligatory.

6.3.1 Once the grouting of a hole has been commenced it should be continued without interruption until completion. In general, grouting should be considered complete when the intake of grout at the desired limiting pressure is less than 2 l/min, averaged over a period of 10 min, for pressures more than 3·5 kg/cm^2 or 1 l/min for pressures lower than 3·5 kg/cm^2.

6.3.2 As far as practical, a continuous flow of grout should be maintained at the desired pressure and the grouting equipment shall be operated to ensure continuous and efficient performance throughout the grouting operation. If any hole continues to absorb large quantities of the thickest pumpable grout at low pressure, the injection may be suspended overnight and then resumed next day.

6.3.3 Should any hole connect to another during injection, the grout should be allowed to escape from the coupled hole till it is of the same consistency as that being injected; the coupled hole should then be capped and the combined holes brought up to pressure and grouting continued. It is not always necessary to grout again through such connected hole. Where leakages of grout occur on the surface, they should be stopped by caulking with wooden wedges, cement, etc.

6.3.4 Grouting shall be stopped whenever pressure gauges register a sudden drop of pressure or the rate of grout absorption increases abruptly or there is any indication of upheaval, disturbance or leakage. In such cases grouting may be resumed at a lower pressure but the efficacy of the grouting operation may be compromised by the temporary interruption.

6.3.5 The control of grout mixtures is not amenable to rules which can be fixed in advance and sufficient discretion should be left to the field personnel. In **7.3.1** the guiding principles for selecting grout mix proportions are discussed. As a general principle grout mixtures should not be thickened, if pressure starts to rise after continuous injection over a period of 10 minutes.

6.3.6 After grouting is completed the grout holes should be closed by means of a valve to maintain the grout pressure for a sufficient period to prevent escape of the grout due to back pressure and flow reversal. For this purpose a period of one hour is generally sufficient, however, this should be verified by trial.

6.4 Testing for Efficacy of Grouting — This testing may be done by drilling the holes in between the grout planes and by testing water intake in these test holes. If this is compared with the water test made before the grouting, this water test will give an indication of the efficacy of grouting. Further grouting of this test hole and intake in this hole will give further indications. It is only after these tests that the engineer-in-charge may decide on increasing the number of grout planes if required.

7. GROUTING EQUIPMENT

7.1 Grouting System Arrangements

7.1.1 *Manifold or Header* — A grout manifold is a 'T' arrangement of pipe and various fittings, such as couplings, nipples, unions, tee valves and pressure gauge all attached to the grout hole. The functions of the manifold are the following:

a) To permit regulation of the flow of grout into the hole,
b) To maintain the desired allowable grout pressure,
c) To allow any excess grout to be drained from the system or returned to the agitator tank for recirculation, and
d) To close off the hole when washing the supply lines.

7.1.1.1 Manifold designs vary and depend on the type of grouting system.

7.1.2 *Single Line System* — The single line system, as the name implies, consists of one grout supply line from the pump to the grouting manifold at the hole.

7.1.3 *Circulating System* — The circulating system requires two pipe lines, a supply line from the grout pump to the grout hole and a return line from the grout hole to the agitating pump. By opening the supply and grout-hole valves, grout is forced into the hole as required. Pressure is maintained by adjusting either the supply valve or the return valve or

both. Complete control of the pressure is maintained at the hole. No grout is wasted when washing out the grout lines and close control of the grouting operations is maintained. When direct electric or diesel drive pumps are employed, use of a return line is obligatory.

7.2 General Requirements of Grouting Equipment

7.2.1 The grouting equipment should meet the following requirements:

a) Of sufficient size of supply to the maximum demand for grout,
b) Capable of prolonged operation at anticipated maximum pressures,
c) Of sufficiently rugged construction to minimize delays from failure of some essential part,
d) Permit quick cleaning by washing, and
e) Provide quick access to key parts in case of mechanical failure.

7.2.1.1 Continuity of operations is mandatory not only for efficiency but also for effectiveness of the grouting.

7.2.2 *Grout Mixers* — Mixers are generally cylindrical in shape, with the axis either horizontal or vertical and equipped with a system of power-driven paddles for mixing. Some mixers use a high-speed centrifugal pump for mixing. Vertical, barrel-type mixers have proved satisfactory when small mixers are required for use in confined or limited working spaces. This type of mixer consists essentially of a vertical barrel having a shaft with blades for mixing, driven by a motor mounted on top of the mixer above the barrel. Centrifugal pump mixers mix the grout by recirculating it through a high revolution per minute centrifugal pump.

7.2.3 *Grout Pumps* — A pump suitable for grouting should permit close control of pressures, allow a flexible rate of injection and be designed to minimize clogging of valves and port. Grout pumps are of three types, piston, screw and centrifugal. Piston type pumps may be powered by compressed air, or electric motors. One of the most common types is the air-driven duplex, double acting pump with special fittings for cement-grout service. Screw type pumps are simple to operate, easy to clean and can be readily transported because of their light weight. They are particularly advantageous in grouting 'slow take' holes and in pumping sand-cement grouts. Centrifugal pumps in a number of models have been used for pressure grouting. Where large volumes of grout are to be pumped rapidly at low pressure centrifugal pumps are satisfactory. Their weak points are the bearings that may be cut out by the abrasive action of the grout, and the difficulty in cleaning. They are not satisfactory for slow pumping over prolonged periods.

7.2.3.1 For underground work the air-driven duplex double acting pumps are recommended to be used as it is possible to vary the pressure and intake in a wide range easily with such pumps.

7.2.3.2 Pneumatic grouting machines are not recommended for consolidation grouting because they do not readily admit of control on grouting pressure, at will during the grouting operations. With pneumatic machines it will not be possible to start with low pressure and build up the pressures gradually. However, for contact grouting where grouting is done at low pressure, and where the control of pressure is not very important and especially where the contact grouting is done with mix of cement sand mortar, these grouters are recommended to be used.

7.2.3.3 Although the use of the duplex type pump is better for contact grouting, the pumping of cement mortar grout through such machine is slow and costlier than injecting grout with pneumatic grouters.

7.3 Grouting Materials

7.3.1 Grouting should be done with cement conforming to IS : 269-1967* or IS : 455-1967†.

7.3.2 *Grout Mix* — Grout mixes may vary from a very thin mixture of 20 : 1 to thick mixture of 0·5 : 1 (ratios of weight of water and cement). The normal range mixtures falls between 5 : 1 to 0·8 : 1. The choice of the grout mixtures at the start of the grouting operations may be based on the results of water tests prior to grouting or intake of holes already grouted.

7.3.3 If the grout is too thick, passage of grout travel may get obstructed at a short distance and the fine seams may not be filled up. On the other hand if thin grout is continued for too long a time the grouting operation may get unduly prolonged and may be rendered unduly expensive. No general rules may be stipulated regarding the manner in which the thickening of the grout is to be carried out. The appropriate sequence for every site may be decided after a review of the results of initial grouting. As a guide the mix should be thickened if there is no increase in the pressure after a continuous grouting of about 10 min or after two batches of four bags of cement each have been pumped. In the case of contact grouting the mix generally used may be the thickest mix namely 0·5 to 1.

7.3.4 *Additives in Grouting* — It is generally advisable to carry out both pack grouting and consolidation grouting with mixture of cement and water only. If intake is heavy and it is desired to keep down the cost of grouting, the grout may be thickened by using inert material like pozzolanas, fine sand, rock powder, clay or bentonite.

---

*Specification for ordinary, rapid-hardening and low heat Portland cement (*second revision*).

†Specification for Portland blastfurnace slag cement.

7.3.5 Where it is necessary to inject porous or finely fissured rocks which will not accept cement or where it is necessary to block flowing water, chemical grouts with or without cement may be tried. In such cases additives to accelerate the setting time of cement may also be used. Where such additives are used along with cement it is recommended that the additives should be added at the manifold and not in the grout mixture or in the grout pump to avoid the danger of clogging of the grout lines in case of any interruptions.

8. RECORDS

8.1 It is necessary that accurate records of grouting should be maintained regularly so that it is possible for the engineer-in-charge to make any changes that may be required in grouting patterns or sequences. The records to be maintained shall indicate the following data:

a) Co-ordinate of the hole;

b) Depth of the hole;

c) Features of grouting — pack grouting or consolidation grouting;

d) Results of pressure test, if carried out;

e) Time and date of starting the grouting of the hole;

f) Consumption of grout separately for each type of mix used and the time required to inject the particular mix along with the pressure developed during the grouting of each mix;

g) Time of completion of hole;

h) Total quantity of cement and other materials used for each hole;

j) Cement wasted;

k) Stoppages, if any, and reasons for stoppage; and

m) From this data the rate of injection of each type of mix for the pressure range should be calculated and recorded.

8.2 Remarks — Remarks should indicate if any holes are abandoned, reasons for abandoning the holes and also the connections to any other holes, leakage, if any, and any other information.

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones : 331 01 31 331 13 75

Telegrams : Manaksanstha (Common to all Offices)

Regional Offices :

		Telephone
Central	: Manak Bhavan, 9, Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
* Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	37 86 62
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	2 18 43
Southern	: C.I.T. Campus, IV Cross Road, MADRAS 600113	41 29 16
† Western	: Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	6 32 92 95

Branch Offices :

'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48
‡ Peenya Industrial Area, 1st Stage, Bangalore-Tumkur Road, BANGALORE 560058	39 49 55
Gangotri Complex, 5th Floor, Bhadbhada Road, T.T. Nagar, BHOPAL 462003	55 40 21
Plot No. 82/83, Lewis Road, BHUBANESHWAR 751002	5 36 27
Kalai Kathir Building, 6/48-A Avanasi Road, COIMBATORE 641037	2 67 05
Quality Marking Centre, N.H. IV, N.I.T., FARIDABAD 121001	—
Savitri Complex, 116 G. T. Road, GHAZIABAD 201001	8-71 19 96
53/5 Ward No. 29, R.G. Barua Road, 5th By-lane, GUWAHATI 781003	3 31 77
5-8-56C L. N. Gupta Marg, (Nampally Station Road) HYDERABAD 500001	23 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	6 34 71
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76
Plot No. A-9, House No. 561/63, Sindhu Nagar, Kanpur Road, LUCKNOW 226005	5 55 07
Patliputra Industrial Estate, PATNA 800013	6 23 05
District Industries Centre Complex, Bagh-e-Ali Maidan, SRINAGAR 190011	—
T. C. No. 14/1421, University P. O., Palayam, THIRUVANANTHAPURAM 695034	6 21 04

Inspection Offices (With Sale Point) :

Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	52 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, CALCUTTA	27 68 00
† Sales Office is at Novelty Chambers, Grant Road, BOMBAY	89 65 28
‡ Sales Office is at Unity Building, Narasimharaja Square, BANGALORE	22 39 71

Reprography Unit, BIS, New Delhi, India